No. 106. Vol. 18.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE ONE HUNDRED AND FORTY-THIRD GENERAL MEETING of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, London, W.C. 2, on Tuesday, May 10th, 1932, Mr. JAMES KEWLEY, M.A., F.I.C., President, occupying the Chair.

The Secretary read the names of the candidates nominated for election and the following list of members elected :—

As Transfer to Member.—Walter Leslie Forster.

As Associate Member.—Col. Orazio Guerritore.

As Transfer to Associate Member.—John Thomas Warde.

As Associates.—Harry Hyams, John McVittie Moresby.

The President said that Mr. Beeby Thompson was so well known to members as to need no introduction, and the following paper was then read :—

Modern Oil Production Problems.

By A. BEEBY THOMPSON, O.B.E., M.I.Mech.E., M.Inst.M.M., F.G.S. (Vice-President).

THE almost kaleidoscopic changes in sentiment and technique which have confronted the production engineer in recent years are almost bewildering in their magnitude and variety. No sooner is one problem solved to the immediate satisfaction of the majority than new views obtain general recognition and necessitate another change of plans and further expense in plant. Ever increasing competition in the oil world is forcing upon operators economies and efficiencies which are only made possible by increasing improvements in material and design of machinery and appliances to meet new conditions. No unbiased observer can feel anything but admiration for the metallurgists and engineers who have so quickly evolved and put into usage metals and alloys, which allow depths of 10,000 ft. and pressures of 5000 lb. to be handled with as much safety as those of a third of these a few years ago. But the evolution would have been impossible had not the human element responded with as much alacrity to the new conditions. To-day, scientific talent is being expended in studying a host of questions which are more or less obscure, and every day new facts are brought to light which assist in the solution of problems which are exercising the minds of production engineers.

Equitable Division of Oil in Pools.

Certainly the most striking development in thought and practice, actuated primarily by self-interest, is the popular acceptance by oil producers of the principle of unit operation of oilfields. Although some of us had consistently and insistently in words and writings referred to the obvious evils of uncontrolled offsetting, with irrational spacing and placing of wells, it had become such an accepted custom that Courts of Law in U.S.A. awarded damages to claimants when leaseholders failed to drill offset wells notwithstanding the omission in leases of any drilling obligations. The law of offsetting had become a recognised principle of oilfield operation and its virtual enforcement in U.S.A. has always been one of the contributing causes for excess production and other abuses.

The equitable distribution of fugitive subsoil minerals to owners of land or proprietors of mineral rights covering an oil pool was no easy matter, for from the time the first well produced in an oil pool a readjustment of oil, gas, and perhaps water, distribution set in. No two oil pools would be likely to present the same characteristics, so that no simple rule could be framed and made generally applicable. For example, a single or several strategically placed wells might commercially exhaust a limestone pool; and there is always the difficulty of defining the superficial and vertical limits of the pool until a late stage in its development. Only within recent years has the necessary data become available to permit of any reasonable approximations of recoverable oil contents of oil pools being estimated, nor was the full importance of orderly and methodical development generally realised.

That enormous expenditure on superfluous drilling would be saved by proper spacing of wells, and that the retention of gas would prolong the life and increase the ultimate yield of oil pools was generally agreed, but it was considered beyond human powers to introduce measures which would satisfy the many parties interested in spotted acreage over an oil pool. Over-production of oil and the need for proration of production in some oilfields has shown that amicable agreements can be negotiated by producers, although some settlements can scarcely be called voluntary. One way or another by peaceful persuasion or organised force pressure has been exercised in some oilfields to ensure a general pro-rating of output without throwing unbearable hardships on the majority of participants. The success of these movements in U.S.A. has paved the way for the more ambitious proposals of unit operation of oil pools.

Deep, costly drilling brings in its wake so many new complex problems that thoughtful operators have radically changed their

views concerning ownership of oil which was so long regarded as the fair spoil, if not the sacred rights, of those which could reach it first regardless of the injustice suffered by neighbours, provided only that certain regulations were observed, such as exclusion of water and distance of well from boundary of plot.

A.P.I. Resolution.

Last year the following noteworthy and far-reaching Resolution was passed by the Board of Directors of the American Petroleum Institute dealing with Unit operation, and its acceptance marks a new stage in oilfield thought :—

" Whereas the prevailing practices in the development of oil and gas pools and the production therefrom based upon the capture by each owner in the pool of as much as he can, as fast as he can, regardless of injury to his neighbours, have been proven to be wasteful of those irreplaceable natural resources, inequitable as between owners of the common reservoir, and demoralizing to the whole industry. Now, therefore, be it resolved by the Board of Directors of the A.P.I. that it endorses, and believes the petroleum industry likewise endorses, the principle that each owner of the surface is entitled only to his equitable and rateable share of the recoverable oil and gas and gas energy in the common pool in the proportion which the recoverable reserves underlying his land bear to the recoverable reserves in the pool."

There can be no misunderstanding concerning its meaning and that it should be passed by a body representing the main oil interests of the United States gives to it an importance and authority which can hardly fail to find reflections in every other oil-producing country.

One prominent and respected oil technologist who had functioned as Chairman of the Yates Pool Pro-ration Committee went so far as to say : " I want to state positively that the ultimate aim of pro-ration and of unit operation should be to recover for each leaseholder only that oil which originally underlay his property. In other words, pro-ration and unit operation do away for ever with legalised piracy which says that oil belongs to the man who reduces it to possession."

Dangers of Uncontrolled Flow.

Such high pressures and large outputs are resulting from drilling into deep oil zones that, unless production is scientifically controlled, a whole series of disturbing consequences will ensue, both physical and economic. Uncontrolled or semi-restricted flow causes many oil sands to disintegrate, with the result that casings and fittings are quickly cut away by sand blast action

when pressures are high, and it becomes impossible to shut off the flow. In many cases such loss of control would mean the destruction and loss of the well. The dangers of such have been illustrated by many wild wells which have spread disaster and destruction far afield, whilst indirect losses of indeterminable, yet enormous, amount are suffered by most operators in the field, through the fall of gas pressure and the possible localised advance of edge water. Some of the dangers were vividly impressed upon operators in the Oklahoma City field, where proprietors in their desire to establish a high potential for pro-rationing purposes allowed their wells to flow wide open for a while, with the result that surface control fittings were dangerously cut. As a rule it was possible to return and kill the well with mud fluid and insert new valves and surface connections before control was lost, thereby avoiding disastrous blow outs.

The Moreni fire in Rumania is a striking example of what may occur if a deep high-pressure well gains mastery. This particular well took fire on breaking loose, and after burning for 2½ years and defying all efforts to effect its control or extinction, it was finally snuffed out. The initial flow probably reached 150,000,000 cu. ft. a day, and the total gas losses may be something in the order of 30 to 50,000,000,000 cu. ft. The well eventually cratered, like so many wild wells do, through erosion of casing and disintegration of strata. Another Rumanian well at Gura Ocnitzei in 1931 blew wild and got out of control when drilling into the oil sands and quickly cratered, so that operations at the mouth of the well were rendered impossible. Very fortunately a near-by well, which had been abandoned, was placed at the disposal of the owners, and the flow was suppressed by pumping water against a pressure of 1200 lb. into the oil stratum. Unless such a wild well plugs itself, it is generally necessary to drill a new well alongside to relieve the pressure, so that work can be undertaken at the faulty well. A classical example of such dangers is that of the Dos Bocas well at Geronimo in Mexico, where an entire oil pool was probably exhausted during the few years of its productive activity.

These examples are mentioned merely to illustrate the extent and widespread nature of destruction and loss which follows the failure to control high pressure oil sources. As pressures are mainly a function of depth and the amount of gas held in solution by the oil is approximately proportional to the pressure, it is easy to see why the penetration of deep-seated oil-bearing strata must be conducted with extreme care and with ample safety devices to prevent a blow out. It is partly for this reason that so much care is now exercised in using a mud of sufficient weight and of suitable properties to more than counterbalance any likely pressures, yet

impose no impracticable frictional or other factor. To ensure a continuance of such properties it is necessary to have a reserve of mud and to provide means for reconditioning circulating mud by freeing it of occluded gas and suspended cuttings. Where dangerous conditions are known or suspected many wells are furnished with means for working under high surface pressure and snubbing the drill pipe, tools, flow pipe, etc., into the well. Sometimes new or reconditioned mud must be circulated for days before it is safe to handle the well.

Results of Deep Drilling.

The reason for stressing these points is to make it clear that operations in the future dealing with deep sources must of necessity arrange for controlled output, and that, however anxious a producer may be to benefit at the expense of his neighbour, he is no longer able to do so, except by an enormous outlay in excess drilling. Producers also recognise to-day the value of gas as a propulsion agent for the oil contained in the pores, crevices, etc., of the oil-bearing rocks, and in consequence they are all desirous of maintaining a low gas-oil ratio. Furthermore, they appreciate the importance of regulating as far as possible the rate of depletion, so that pressure readjustments can be equalised to avoid irregular influxes of edge or bottom water. Operators are also perturbed by the difficulties of raising oil from very deep wells when they have ceased to flow and the fluid level falls. Unitization has found its supporters as a result of a recognition of those accepted principles plus the urgent need for controlling the higher production from the deep sources of supply.

Deep drilling, with its consequent problems, is compelling a degree of co-operation never before experienced between producers sharing acreage in an oil pool, and unquestionably this has facilitated the friendly reception given to the plan of unit operation. Some fortunate concerns with ample means and commendable courage and foresight have been able to secure for themselves the whole probable area covered by an oilfield, but this is the exception and not the rule, and to-day competitive drilling and boundary fights continue, though as a rule with less aggression than formerly as it is a costly game. Recent examples of note are Spindle Top, Texas, and the Venice field, California, but Rumania and Burma afford striking examples. Such line fights are the natural evils of a system which has gained general recognition and they cast no particular discredit upon those who take part, but they serve to show the needless and terrible losses sustained by oil producers in following a practice based on the survival of the fittest and supported by customs which it seemed impossible to change.

Pro-rationing of Output.

Curtailment of output by pro-rationing was one of the earliest methods of meeting problems of over-production in U.S.A. At first a purely voluntary movement with popular support it assisted in stabilising prices and restraining output, although it was not possible to persuade all producers to join the scheme; but at a later period various public bodies with questionable rights asserted authority and managed to divest innocent-looking laws with extraordinary powers. Under the pretext of checking "unreasonable" waste of natural resources public authorities were able to place hindrances and restrictions on reckless or capricious operations in new fields, where a sudden flood of oil demoralised markets and penalised operators who conducted their operations in a rational fashion.

Most of the pertinent laws appear to have been interpreted to meet circumstances, and their enforcement or disregard has likewise been determined by events and popular demand. At all times the Sherman law, originally designed to prevent restraint on trade, has been conveniently invoked at critical junctures to check dangerous combinations, monopolies and such like, which would reflect hardships on the community. It has at least proved a useful bogy to raise when advocates of curtailments proceeded too fast. The Sherman law has been the subject of much hostile criticism in recent years mainly because its meaning has been deflected from its original purpose of stopping conspiracies.

The railroad Commissioners of States have usually been the authority through which proration orders were issued, but their enforcement by injunctions or exactions of penalties for non-compliance has always been hotly contested by a few and made difficult. Confusion of physical with economic waste has been a disputable issue when violation has been charged, and the modern application of the term waste usually implies both forms in some manner. The East Texas enforcement of prorationing by State troops was certainly associated with the price question and not the mere dissipation of gas.

Proration as practised to-day is unquestionably open to grave objection notwithstanding its popularity, and the general recognition of its worth as a palliative does not deprive it of its bad features. The common plan of ascertaining the potential of a well by open or restricted flow for a limited number of hours is obviously liable to give very wrong values, and it so frequently involves dangers. In order to obtain a maximum potential the nearest safe, or more often the largest flow which it is confidently hoped will not spell disaster, is encouraged with the result that a

potential is established which bears little relationship to the truth. One has only to see the extravagant potentials fixed for a number of oil pools in U.S.A. to realise that such outputs could only be sustained for a very brief period if the field was permitted to run freely. A good example is the Oklahoma City field where as recently as March last some 675 wells eligible for production were allocated a potential of 3,237,000 barrels, an amount nearly equal to the world's present output. As an example of the high potentials for single 6500 ft. wells established in one month may be mentioned a few typical examples: (*a*) 330 barrels in 9 minutes and cut surface fittings so badly that it had to be closed; (*b*) 6075 barrels in first hour; (*c*) 961 barrels in 30 minutes on 4 in. choke against 250 lb. pressure.

The great East Texas field of Rusk and Gregg counties, which is at the moment the greatest menace to price stability in U.S.A., has a proved area of about 100,000 acres, and is thought to be good for over 1,000,000,000 barrels of oil. The 4750—3500 ft. wells with high measured potentials are prorated at 71 barrels a day in order to keep the output of the field to about 325,000 barrels a day, and it is purposed to reduce the allowable as additional wells come into production.

The publication of these misleading and often illusory potentials is a grave menace to the stability of the oil industry, for by creating distrust in the future it causes unnecessary depression of prices and anxiety amongst shareholders.

Unit Operation.

Unit operation or unitization of oil pools has been the dream of most of us who have witnessed the pre-war conditions in Russia where 27 acres officially constituted an oil lease, in Rumania and Galicia where peasant holdings were often cut into small strips a few yards wide, and in U.S.A. where town site drilling was practised or speculators sub-divided acreage into small parcels barely large enough to hold a derrick. The Yenangyaung oilfield of Burma was mainly developed by operating Burman leases, each having a diameter of 60 ft. only, so that development was in the nature of a jig-saw puzzle only made possible by mutual concessions and goodwill.

A few fields have already been developed on a unit plan with wonderful success, the outstanding example being Persia, but in U.S.A. quite a few fields are being worked on a unit plan which more or less fulfils the aspirations of those directing the enterprise.

Technologists in close touch with oilfield events confidently believe that they will in time be able to unfold a scheme whereby the equitable proportion of each lease or block of acreage can be

reasonably safely calculated from well logs, core analysis and a more comprehensive understanding of subsoil phenomena. Serious efforts are being made to evolve scientific methods of fairly allocating the production of oil pools shared by many competing interests. Obviously the necessary data for such calculations would only be known at a somewhat late stage in the development of a field, but by pooling a certain percentage of the proceeds of joint action, it might be possible to provide for readjustments from time to time so that each working interest derived his share of the oil which might reasonably be expected to have underlain his land.

There are obviously many difficulties connected with a programme of this character, and at present such widely differing views are held concerning the distribution of oil, gas and water, and their usefulness, that only by a very large measure of self-sacrifice and compromise could it be entertained. Perhaps the stabilisation of prices at a profitable level by systematic co-operation and unit operation of fields might compensate for the sacrifice of competition, although one instinctively fears the consequences of removing the incentive of competition in industry and in life generally. Anything which tends to impede or suppress individuality and enterprise is likely to be harmful to progress.

Doubtless many hold views concerning the ways in which unit operation might be approached, but few intimately connected with oilfield practice under-estimate its difficulties. A considerable amount of compromise is essential to satisfy the claims of those owning acreage with varying relationship to the structure. Crestal and flank locations have problematical, perhaps doubtful values, yet their inclusion in a scheme is essential to ensure the complete command of the gas and oil in the oil pool. Each and every oil horizon, where there are several, may cover a different area, and the points of maximum saturation and richness may not superimpose each other as surface dips only roughly reflect the structure at great depth, and there are no known means of safely projecting the shape of folds mathematically, graphically or geophysically; it is by drilling alone that the structure can be elucidated and the richness of the various oil-bearing zones ascertained. This uncertainty has got to be realised when defining the acreage which on any structure should be placed under unit operation, and permission would appear desirable to expand or contract the acreage coming under a unit plan, as drilling brought to light new data enlarging or diminishing the productive area.

As regards the relative merits of plots with relationship to the structure, it is suggested that no discriminations in value can be made in our present incomplete state of knowledge. With unit

control the most valuable land occupies an indeterminate belt somewhere intermediate between the high points where gas is concentrated and the edge-water. Under competitive operation on one could predict who would benefit most when developing a structure, as so many independent factors operate. Those with holdings near the crest could waste gas and deprive the oil lower down the flank of much of its propulsive energy, and operators low down on the flanks could by disorderly drilling let edge water rise. As submission to an acknowledged authority entails a complete abnegation of rights, it is submitted that all those with acreage over the productive zones are entitled to equal rights, but whether this should apply to all productive horizons when a succession is developed on the structure appears a fair subject for debate and likely to open highly contentious questions.

The legal aspect is another matter likely to cause lively discussion and much litigation unless official recognition and support to such schemes is forthcoming, but this may not prove insurmountable if the goodwill and common-sense of all can be ensured. One case only can be recalled where an effort was made to allocate to owners of the surface their exact proportion of a fugitive mineral, and that was the pitch deposits of La Brea, around the Trinidad Lake. On excavating for pitch below a surface bed of soil asphalt from neighbouring lands flowed into the pit to fill the space made, with the result that neighbouring landowners were deprived of some of their deposit and the surface level was lowered. The object was to relieve the workers from almost perpetual litigation which ensued, but if the allocation of oil entailed as much trouble in proportion to tonnage as Trinidad, there would be little hope of unit operation succeeding. However, a decision of the Supreme Court of Oklahoma has decided that the State is empowered to regulate the taking of oil from a common source with due regard to the equitable share of all holders.

Royalty owners will need satisfying that their rights are being adequately protected by any unit operation. Obviously they will benefit ultimately and as a whole, but the longer wait will not appeal to many who recall the quick wealth gained by others in the past. Development leases will have to be remodelled to meet the new conditions and such details as drilling obligations will have to be omitted.

Another reason for furthering unitization schemes is the desire to apply air, gas or water drives when fields are approaching commercial exhaustion, or to introduce repressuring operations at an early stage in the process of depletion. Unless a large unbroken block can be reserved for such operations, these methods are virtually ruled out of consideration.

Production Methods.

Modern production methods in deep territory resolve themselves into three main divisions: (*a*) Production during the natural flowing period when there is sufficient gas pressure to cause natural flow; (*b*) production by artificial methods when the gas is insufficient to lift the oil to the surface unaided; (*c*) recovery of dregs.

Controlled Flow and Gas-Oil Ratio.

High-pressure wells are now almost exclusively flowed through beans or nozzles, the number and size of which can be varied to suit the well. A rate of discharge is adjusted to keep the sand and gas-oil ratios within some more or less hypothetical limits which, whilst avoiding undue wear of nozzles and fittings, constitute efficient practice with due regard to local conditions. No general rule for the gas-oil ratio can be prescribed, for whereas in some territory it can be kept very low, 100 to 500 cu. ft. per barrel, in other fields it may have to be very high, 1000 to 3000 cu. ft. per barrel. Mexico afforded an example of exceedingly low natural gas-oil ratios, whilst the greatest gas-oil ratios are recorded from the light-oil fields where production is rather of the nature of a drip or condensate from wet-gas. Turner Valley, Alberta, Canada, and Kettleman Hills, California, afford typical examples of high ratios, the former varying from 19,000 to 731,000 cu. ft. per barrel, the latter from 20,000 to 30,000 cu. ft. per barrels of crude. In the Turner Valley field of Alberta, the Provincial Government decided to impose restrictions on rate of flow in order to conserve gas for which there is no available market beyond some very variable amount dependent upon seasons. (Peak, 60,000,000 cu. ft. day.) It has been estimated that the total gas production of Turner Valley prior to restriction had reached 600,000,000 cu. ft. a day. In December last, the gas-oil ratios averaged 136,000 cu. ft. per barrel. This will probably be the first official application of such a ruling to a major oilfield where there is an immediate market for all the oil that could be produced, although the principle of conservation has been accepted for years. Obviously there are two sides to the question, and without full acquaintance with all facts it is impossible to decide whether the advantages of this action outweigh its disadvantages. No one disputes the importance of conservation of valuable resources, but hitherto no official body has had the courage to restrict the development of an oilfield to the market for the gas produced with the oil when there was a free and profitable market for the oil. About

5,000,000 cu. ft. daily are being returned to Bow Island to recharge the old gas field, the surplus supplies field purposes as well as Calgary and other Alberta towns.

This arbitrary action of the Government will undoubtedly cause hardships, and again raises the question whether under certain circumstances the duty of guaranteeing the interest on funds expended in piping gas to distant markets or returning surplus gas to earth reservoirs, if it is feasible, should not devolve on the Authorities. Failing this, the Government might have financed operations to test whether the gas zone was underlain by a deeper heavy oil zone, as at Kettleman Hills, for if such were the case the Government might reasonably have enforced the preservation of the gas and compelled operators to drill to the main oil horizon below. The action of the Alberta Government is, however, symtomatic of the advanced reasoning concerning resources of National importance, and it raises the vexed question of how far it is safe to preserve natural resources for the benefit of future generations. In this case it is not a question of reducing the gas-oil ratio, but conservation in its strictest sense in a district which shows no immediate signs of being industrialised, whilst it is too far from many large cities to permit of the economic transport of the gas.

The Kettleman Hills situation in California led to drastic measures of control for somewhat different reasons to that of Turner Valley, for so prolific were the wells, and so extensive the field, that its unrestricted development would, in a very short time, have upset the oil market of the U.S.A. A quick realisation of the danger of the situation led to a close co-operation of interests with official State and Federal cognizance and help, and a decision was reached to exploit the field on an approved unit basis. The output of this great field with a calculated potential that reaches colossal figures based on incomplete data has been kept to about 63,000 barrels a day.

As before stated, the control of deep high pressure flowing wells is not so much due to the virtuous conduct of the producer as to dire necessity, for once out of control their recapture is often impossible and their total destruction is generally certain where the oil issues from sandy sediments. This is not all, however, for the unrestricted flow of many thousands of barrels of oil daily mingled with perhaps 50,000,000 to 100,000,000 cu. ft. of gas constitute a menace to life and property over a wide district. Enormous sums may have to be spent on operations to suppress blow outs and permanent injury may be sustained by the major part of an oilfield through the loss of the precious energy which should have been retained for the orderly and gradual depletion of the pool.

Gas in Oil Measures.

Divergent views are doubtless held concerning the mode of occurrence and the distribution of gas in oil measures. Undoubtedly gas-bearing strata more or less isolated from oil-carrying sands exist in some oilfields, but if granted this should not be used as an excuse for wasting gas. Even if it eventually fails to gain admission to the oil sands as the pressure is relieved, such supplies can be put to very valuable uses at a later period of the fields history as fuel, or for re-pressuring or lifting oil from wells where the pressure has fallen too low to cause natural flow, and there is often insufficient for fuel purposes in the expiring days of an oilfield.

Until recent years no useful estimates of gas ratios were obtainable, and the early calculations of Lewis were based on the rough data available at that time, but evidence points to the fact that much more gas is present in oil measures than could be absorbed by the oil contents. This surplus gas must either exist as gas in certain beds or in the higher parts of sandy lenticles, or be dissolved in edge water on the flanks of structures and gradually released as the pressure on the field falls. Doubts may be cast concerning the source of gas which so often is associated with intermediate waters in oil measures, but no question can arise when edge water heavily charged with gas is struck. Many of those who operated in Mexico will have noticed how highly charged with gas were the hot waters which followed the oil on its exhaustion with the ascent of edge or bottom water. The famous Dos Bocas well, to which allusion has already been made, flowed about 30,000,000 barrels daily of water heavily charged with gas after the expulsion of perhaps some 100,000,000 barrels of oil. In the Russian fields intermediate waters were frequently saturated with gas which ejected the contents of bailers used for cleaning the wells.

The view is submitted that the waters associated with oilfields may constitute a very useful storage for excess gas, which is evolved and enters the oil sand to assist the process of removal when the pressures on the oil sands decrease. In the same way the gas dissolved in edge water may be to some extent responsible for the tongues of water which advance so quickly towards producing wells on the flanks of structures where pressures are not equalised by orderly developments. Be this as it may, the gradual and well spread relief of pressure off a structure should be of benefit in permitting the profitable use of gases not dissolved in the oil.

Earth Pressures.

Those with intimate field experience appreciate how often theoretical deductions fail to materialise in practice, for the very simple reason that it is impossible to reconstruct in the mind or to reproduce in the laboratory the numerous contributing factors that operate in the earth. There was a time when the writer questioned reported gas and water pressures far in excess of or below those due to a hydrostatic pressure based on near-by land levels, and a mass of collected data indicated that such was generally the case to the usual depths then exploited of 2000 to 3000 ft. Deeper drilling is, however, proving that most erratic and unexpected pressures are being encountered in deep wells. Static pressures far below and far above those due to a hydrostatic column are reported, and there is often no progressive gradation of pressures with depth. Beyond certain depths to which there is usually a fairly regular pressure gradient somewhat below that due to a hydrostatic head based on present-day levels, a zone is often reached where the pressures are very erratic. Specially abnormal conditions seem to develop at depths of about 4000 ft. on defined anticlinal structure where peak pressures become very high due to compressional forces and the flexures are often much sharper. The risk of meeting pressures substantially in excess of those that could be attributed to present-day hydrostatic conditions is compelling drillers to employ mud fluids with a weight far in excess of that which would normally neutralise all pressures that would be expected, and allow a good margin for lightening by gas cutting. But this is now often regarded as insufficient, and provision is made for drilling with circulating fluid under a high surface pressure in addition, the tools being inserted and withdrawn through a lock, control head, or blow-out preventer.

Only within recent years have precautions been taken to measure and control pressures ; indeed, the main object of most producers was to extract the maximum amount of fluid in the minimum of time with the least trouble, regardless of thoughts of conservation. Open flows were encouraged, and swabbing, bailing and air/gas lift were employed to recover a maximum of production when natural eruptions diminished or ceased ; consequently, very little trustworthy data is available concerning pressures down to depths of, say, 3000 ft.

One can recall such incidents as the neurotic development of the Powell field of Texas, where on the cessation of natural flow compressors were hastily despatched to the field by passenger train from the works, and in some cases the whole cost of purchase, transport and erection was repaid within a few days of their

installation. One well was stated to have given by air-lift 113,000 barrels of oil in 21 days, and increases from a few hundred to one or two thousand barrels daily were frequent. As oil came from a limestone formation there were no sand troubles to endanger the well or fittings, and water encroachment was the only likely complication.

Earth pressures in excess of those due to a hydrostatic head have been recorded in many deep wells of recent years. Sometimes the pressures are so high that positive danger is incurred by totally closing the well. These pressures are not confined to oil or gas sources, but water strata exhibit the same characteristics of abnormal pressures. One is therefore constrained to deduce that the excessive pressures result from rock compression and not to gas production *in situ*. In some cases pressures in excess of a hydrostatic measured by present-day land levels may be inherited from former land elevations, but where irregular pressures are recorded this would appear to be less likely. However, the whole problem is greatly complicated by the irregularity of pressures recorded at depth, for there is now no longer any doubt that at great depths conditions exist which were less often found at shallow depths. At one place mud will be freely absorbed, at another it will be thinned by admixture with inflowing water, and at times great difficulty is found in re-establishing circulation. Sometimes circulation can only be maintained by a careful balancing of pressure. Too heavy a mud will drive fluid into the formation : too light a mud will be thinned till the cuttings cannot be lifted and a delicate balance has to be found when two strata with opposite properties are simultaneously exposed in the hole.

Notice was called to a well where at one time liquid was freely absorbed, and at another time it was expelled, indicating the exposure of two near by sources with opposite properties where the balance was occasionally upset by changing conditions.

The point it is desired to stress is that, contrary to general expectations, pressures do not necessarily increase with depth and that low static fluid levels are met with below high pressure zones. Perhaps some of our geological associates will be able to explain these anomalies which, to the author, appear so unnatural. Only one very unconvincing and inconclusive theory suggests itself as a possible explanation for low static oil pressures below high pressure zones—namely, that the gas pressure in the deeper sources has been relieved by escape into the higher zones through the medium of faults during the exploitation of the upper sources. This could obviously only apply to cases where the upper richer oil sands were developed prior to drilling deeper.

It seems strange that the time element, which has been so conveniently introduced to explain so many of our migration theories, should have failed to bring about pressure equalisation in the earth.

Flow-tubing and Chokes.

It is the usual practice to-day to insert flow tubing before bringing a well into production. Where the well can be kept dead by mud fluid the insertion of the tubing is a simple and straightforward process, but where there is danger of a blow-out or high pressures collect, the tubing must be inserted through a suitable head piece and the first few hundred feet may have to be snubbed into the well. A size of tubing is determined to suit the particular well, but considerable thought has been given to the question of tubing size to suit different conditions in recent years. Obviously no design of tubing can function equally well under the changing conditions of oil well pressures, and in the majority of cases the most efficient flow of a well can only be ascertained by trial. The usefulness of a taper tube was first ventilated with the idea of taking advantage of the expanding gas in the ascending column of fluid, but only a make-shift alternative is practicable by using a larger diameter tube at intervals. A far better arrangement was to control the admission of fluids into the piping by a bottom-hole nozzle, preferably so designed that the size of orifice could be changed. A number of these have now been introduced so that the rate of entry of oil can be adjusted at will to suit the changing conditions of the well or other considerations. This is by far the most important innovation of recent years dealing with flowing production problems.

One feature only arouses misgivings concerning the general success of bottom hole beans, namely, the production of emulsions where water is present, for the conditions would appear peculiarly favourable for their formation. Their formation at the base of the well would introduce unexpected and variable frictional elements which would upset normal flow and efficiencies and might result in refractory and rebellious mixtures. No data bearing on this question has come to the writer's notice, but it would appear a very likely contingency, and may restrict their use.

Small Hole Drilling.

For several years the writer has been an advocate of small hole drilling to deep sands, but has, perhaps, very naturally found strong opposition from the drilling fraternity. There is no intention of denying the difficulties and dangers of drilling small

holes, but accidents in drilling are becoming fewer and fewer with the use of so many appliances for correcting wrongs, recording deflection, weights on tools, etc. Executive officers of some of the great U.S.A. Companies have stated that whereas formerly they reached their offices in trepidation in the morning to read of the many twist-offs and accidents, they now received the news of a single accident with some concern. In Rumania large workshops designed to do little else than repair broken tools and plant and make fishing tools have been almost closed due to the transfer from the old percussion-flush system to rotary.

When fishing was one of the anxieties and occupations of the drilling department, there was a very natural indisposition to drill small holes, but this fear no longer exists, and the newer types of hydraulic-feed, rotary drills provide for very small holes when called for.

Most oilfield workers in loose-sand fields must have observed how wells of small diameter completed in the past as such, due to a succession of accidents and not by design, have given much larger and more sustained flows than those of larger diameter. This was very obviously due to the restriction of flow occasioned by the small size of the casing, for whereas those of large diameter soon suffered some form of damage due to excessive inrush of sand, the more restricted flow in the small casing did not encourage such a disintegration of the sand. But in addition to the natural restriction of flow the use of smaller casings and fittings to deal with high pressures is a safety measure provided effective means can be adopted to prevent a flow of fluid until all is in readiness for production. With suitable surface equipment and preparations it is possible to provide, in case of emergency, for the wells to flow through the drill pipe, a valve and outlet in the Kelly permitting the pump to be shut off and the oil to be beaned in the ordinary way.

Regarding the safety of drilling small holes to great depth, the fact should not be overlooked that present technique has been advanced so far that sidetracking is viewed with equanimity and looked upon as a normal operation, as it offers no dread to the drillers, so that in case of serious trouble long fishing jobs are not entertained. So great have been the improvements in equipment and in the abilities of the personnel that holes can now be made to drift at will in any desired direction, and it may be that greater use will be made of this development in future to penetrate oil reservoirs at an angle or even to drill two or three holes into the oil stratum so spread that it is tapped at several places. By using oriented deflecting wedges (whipstocks) rotary tools can be guided as required.

Controlled Flow Problems.

Quiet reflection on controlled high pressure flow inevitably leads one to ponder on the economic effects of the reduced velocities occasioned by the lower differential pressures at the well base, for it is the differential and not the pressure that induces movement.

Incidentally, it should be recalled that the potential energy is mainly methane, which is the chief constituent of natural gas that exists in the oil as gas under the prevailing temperatures and pressures. Assuming other conditions to be equal, will this restriction result in as large a proportion of the oil contents of the reservoir rocks being expelled as formerly? There is no apparent reason for suspecting that the deeper oil measures differ in essential characteristics from those met with at shallower depth, so that, apart from the higher pressures and consequently large volumes of gas dissolved in oil, much the same features may be anticipated. If anything the deep reservoir rocks are likely to be more compact and less permeable than those at shallower depths; consequently, with the same thickness and unbroken continuity the oil contents should be somewhat less in quantity. But whereas formerly in shallow drilling operators were virtually compelled to exploit each horizon in turn owing to the impossibility of passing relatively high-pressure, oil-saturated rocks, it is now possible to expose with safety a succession of oil formations before bringing the well into production. On this account the ultimate output of individual, deep, modern wells is likely to exceed very considerably that of old-time wells which could usually only be deepened a limited number of times and at irregular intervals when, perhaps, the deeper sources had already been relieved of their initial energy by aggressive offsets.

Apart from other considerations, it was always claimed that open flow broke down the reservoir rock, set up drainage channels and established a drainage system which played a very important part in sustaining yield when the high pressure was relieved. Few of those acquainted with past methods would disagree with these views, and ample facts could be accumulated to prove the truth of these assertions. Wells penetrating oil-carrying limestone would eject masses of detached rock when allowed to flow unrestricted, and quantities of loose sand or fragments of sandstone would be expelled from sand formations under similar conditions. Shooting with high explosives in hard rocks showing little or no oil, yet known to carry oil, likewise led to large inflows of oil which could never have been obtained without some act of violence. Notwithstanding the risks and dangers involved, open flow and violent eruptions were deliberately encouraged by bailing or swabbing when new wells were brought into production.

Present practice in deep wells prescribes and generally enforces the gentler handling of wells as they come into production, and what concerns the producer most is whether the retention of pressure and maintenance of low gas-oil ratio is going to compensate for the more violent methods of the past. The gradual evolution of gas from a leaky soda-water syphon indicates that gas can escape without performing useful work if control is carried too far, and recent events in Rumania have clearly demonstrated that disturbing consequences are resulting from the new methods. In several of the major deep fields of Rumania, where pressures are in the neighbourhood of 2000 lb., wells which have given excellent outputs under restricted flow have gradually developed increased gas-oil ratios until they become practically gas producers. By using larger beans oil might be induced to return, but the gas-oil ratio may reach 20,000 to 50,000 cu. ft. per brl., a quantity which arouses official and unofficial criticism. Wells are, in consequence, shut in and the gas area extends by degrees further down the structure, putting other wells in succession out of commission. Doubtless most of the early wells pay out by giving 40,000 to 50,000 tons of oil before they turn to gas, but later ones do not reach the sands soon enough to recoup their outlay before gas replaces the oil. Unless, therefore, operators also possess lands well down the flanks, losses are suffered by owners of plots high on the structure, and those further removed are benefiting considerably by the retention of pressure on the crestal sites.

In the case of Rumania the main production reservoir rock of the Meotic series is a highly porous sandstone with much coarse material saturated with paraffinous oil, and it is being tapped at depths of 5000 to 7000 ft. It would be interesting to obtain samples of the formation where the wells have gone over to gas, in order to ascertain to what extent the sands are depleted of their oil contents.

No very complete and quite satisfactory explanation can be given for the above-described phenomena, nor is it suggested that any more rational handling of wells is permissible, but they serve to indicate that new problems are appearing with the introduction of new methods, and their logical and scientific solution is clearly tied up with unit operation. The new conditions brought about by deeper development, the recognition of new principles, and the restrictions and restraint imposed by official regulations and unofficial pressure have definitely prevented any reversion to the old-time practice of uncontrolled flow, but, on the other hand, everything tends towards co-operation in development where sub-division of surface holdings carrying subsoil rights has led to conflicting interests gaining possession of the leases often with drilling and other onerous obligations.

Wet Gas Fields.

A peculiar and rare type of field is giving cause for much concern to both officials and operators, namely, the light oil or wet gas fields, typically represented to-day by the Turner Valley field of Alberta, Canada, and the Kettleman Hills field of California. The one other outstanding example, and the first of its kind reported, was the Surakhany oilfield of Baku, Russia, the exploitation of which the writer was privileged to witness. Each of these major fields exposed a great thickness of strata carrying high-pressure gas and light oil. The fine unconsolidated sands of the Surakhany field gave enormous flows of gas with light sherry-coloured oil sprays, all of which was unwanted except the kerosene fraction of the oil at that time. On drilling below 1000 ft., heavier crude was struck, and below 1500 ft. the typical Baku 0.880 dark-coloured oils were reached. At Kettleman Hills a heavier normal crude has been struck below the gas zone, but at Turner Valley, where the gas is struck in limestones, it is yet uncertain whether heavy oils underlie the light oil zone.

All the above are essentially gas fields and the wells yield a spray of light oil, but the high value of the gasoline and light oil content of the two present-day fields, coupled with the large flows which are possible without disintegration of the reservoir rock, constitute an almost irresistible temptation to flow them freely. Naturally there is popular opposition to the release of products when the gas/oil ratio is in the neighbourhood of 20,000 to 500,000 cu. ft. per barrel, unless the gas can be put to some useful purpose, and in the deep Californian example the yields of wells are so enormous that unhampered development would entirely upset the gasoline market of U.S.A. The value of gas wasted at Turner Valley represented in heating value twenty to thirty times that of the oil obtained. At 20 cents per 1000 cu. ft. the value of the gas is equivalent to about 9 times that of the oil abstracted.

Frosting of Wells.

Another problem which has arisen in some fields is the freezing of wells as the result of the rapid expansion of the gas. It is no uncommon phenomenon for separators at high pressure oil wells to become frosted and even coated with ice, as the result of the freezing of condensed moisture on all surface fittings, but this is occasional and not general. In all cases the earth temperatures of the oil and gas are connected with depth and bear some relationship to the normal thermal gradient of the earth, although somewhat higher as a rule, but the peculiar feature is that whereas some wells produce under controlled or semi-controlled flow without any considerable reduction of temperature, others cause a

lowering of temperature to far below freezing point. As an example, may be mentioned the contrast between the wells of Kettleman Hills and Oklahoma City field, where in the former the flow of oil is warm, whilst in the latter the surface fittings are frosted even in the hottest weather. The surface equipment on the Turner Valley wells, Alberta, became frosted in consequence of the low temperatures that prevail. As a rule the lowered temperatures of oil discharge does not entail serious consequences, as small quantity of water present with the oil may not cause any accumulation of ice on the interior of the fittings, but when there is danger of this the surface apparatus has to be kept heated by gas jets, steam coils or other means.

Freezing of Wells.

A much more serious condition arises from the formation of ice in the well itself, as well as in the leads from the well due to the presence of water with the oil. Serious accidents have occurred through the sudden ejection of a wad of ice from a frozen lead line, and the unobserved restriction of flow by ice in a flow line might cause very dangerous pressure conditions. Only one field has, to the author's knowledge, presented examples of ice forming in the well itself—viz., the Turner Valley of Alberta—and for a time its formation in wells introduced very serious and troublesome production problems. Eventually the problem was solved by adopting more careful measures for excluding water and using a circulation of oil for drilling into the oil-bearing limestone.

No satisfactory explanation has yet been forthcoming to explain the widely different temperature variations of the fluid expelled from oil wells where the nature of the oil and the methods of flowing the well are much the same. The instances mentioned are not isolated freak wells but characterise a class, and no standardised method of operation or control was in force. The low temperatures at particular points would normally be attributed to mechanical influences which cause expansion under favourable conditions, but this explanation does not appear to explain some of the anomalies.

Perhaps some members can advance reasons for this behaviour of wells in certain circumstances where there is no obvious explanation from the casual information available to explain their conduct. In the case of the Turner Valley field, where the oil is derived from limestone, the low temperatures at depth are probably due to circumstances connected with the issue of the gas from fissures in the rock. If the wells are left idle and closed in the temperature rises and the ice thaws, but the freezing process is repeated if a high rate of flow is permitted and water is present.

Since the above was written, a report by Messrs. Rosewarne and Offord has been received, published at the instigation of the Alberta Government, and they attribute the freezing to mechanism associated with the issue of gas from the limestones.

It is a well-known fact that wells yielding high pressure carbon dioxide gas are particularly prone to freeze, and from one gas well in Mexico solidified CO_2 was ejected in consequence of the low temperature reached.

Beaning Gas Wells.

The troubles through freezing of surface equipment of gas wells have been totally overcome in some cases by the use of bottom hole beans on flow tubing. By suitably adjusting the size of bean a differential pressure can be established between the casing and tubing pressures which permits the flowing gas to be sufficiently warmed in its ascent to prevent low temperatures being reached. When gas emerges from beds with a temperature of 120° to 200° F. sufficient interchange of heat can take place in the well to ensure a surface temperature of little less then 60° F. and as no further expansion takes place at the surface, no equipment difficulties are experienced.

Mechanical Extraction.

The mechanical extraction of oil from deep wells is a constant source of thought and anxiety to oil producers. Until now means have been devised to adapt old methods to deep wells solely on account of the great strides made in metallurgy and the heat treatment of metals plus the closest attention to design and mechanical details, such as the fit of pump barrels, the construction of pump rods, the balancing of reciprocating parts, etc., etc., but the raising of oil some 5000 to 10,000 ft. involves pump pressures up to several thousand lbs. per square inch, which demand careful handling, and also the frequent withdrawal of pump barrels and, perhaps, tubing for cleaning out wells introduces a very serious hazard. A time can be envisaged when it may be possible by suitable control of field pressures and re-introduction of fluids to exhaust the oil sands so completely of their contents that the dregs will not be worth the trouble and expense of extraction, but meanwhile the problem has to be met in face of increasing competition.

With the aid of dynamometers the magnitude and distribution of stresses in pump rods has been ascertained, and means have been found to equalise and neutralise unbalanced forces.

It is true that the virtual elimination of crooked holes has lightened the task of the production engineers very considerably, as without doubt many of the past pumping troubles arose from

the deviation of wells from vertical, with consequential unknown frictional elements and excessive wear. Air-gas lift provides a very excellent stop-gap between natural flow and mechanical extraction, but as the process only functions erratically and inefficiently as a spray or intermittently when the level falls below some appreciable percentage of the total lift, it became necessary to consider other methods by which reciprocating parts operated by a connector from the surface could be avoided. All field workers acquainted with air-gas lift working are aware of the usefulness of its intermittent action in some cases, and it was practised regularly in the Russian fields as far back as 1900; but at that time there was no very special incentive to carry the process to extremes by refinements of one kind or another. Where circumstances in Russia forced a departure from orthodox methods of extraction by bailing, pumping, or swabbing, due to deflection or distortion of casing and low level of fluid, the displacement system of lifting oil was introduced, but the addition of even a single valve was a source of trouble where so much floating sand usually accompanied the oil. Very frequently the sand lifted with the oil represented 10 to 20 per cent. of its volumes.

Recent events have driven oilfield operators to re-introduce these old methods of extraction, and it is only natural that, with some 30 years' added experience, improvements in design should be incorporated. It had been the original intention to deal with the gas displacement system in this paper, but Mr. Miller's excellent paper on the subject of February last, followed by that of Mr. Rogers dealing with its use in Rumania, removes this necessity, and it is only intended to make a few pertinent comments on its use and limitations.

Gas Displacement Pump.

The gas displacement pump has been subjected to severe strictures by some who have questioned its efficiency and who regard high efficiency as the major objective in mechanical operations, but many field engineers attach far greater importance to reliability and simplicity. In this connection it is so easy to be misled by statements which only give a part of the story. A high mechanical efficiency obtained by a deep-well pump in a well can be more then offset by troubles which put it out of operation for long periods, such as paraffination of tubing, excessive wear of plungers, cost of maintenance and supervision; and a less efficient apparatus which did not suffer from troubles would prove a far more profitable piece of mechanism. This point of view particularly applies to oilfield work where there is usually an abundance of gas being wasted that will provide the necessary fuel at little expense.

Gas-lift plants have been regularly, but profitably, operated under the most inefficient conditions from a mechanical standpoint, yet the gasoline extracted from the gas which circulated in a closed circuit more than paid all the expenses of operation.

The gas displacement pump appears to fill a much-felt want on oilfields, although a lot more experimenting is necessary before its worth for certain types of well is demonstrated. No provision was made for economising gas in the early designs, but its use in deeper wells has led to the introduction of a chamber valve which removes the necessity of expanding to atmospheric pressure after each expulsion, the gas filling the annular space between the " macaroni " and the outer string of tubes. The Jat chamber valve fulfils this function, but introduces a weak link in the circuit owing to the danger of particles of dirt or rust settling on the valve-seating and stopping its action. Even when the greatest care is exercised to ensure the pipes being clean, it is sometimes found necessary on this score to withdraw and re-insert the outfit several times before it will operate.

The volume of gas needed in a suitably designed installation of piping is not such as to cause most producers serious concern, and it is simply a matter of economy in compressor plant and in some cases of higher main pressures to quicken the periods of discharge. When a pressure supply of gas is available, the whole work can be performed without the aid of compressors, and with suitable arrangements to take care of the large sudden discharges the gas may be made available for fuel. The slugs of oil are ejected with considerable violence, and the outburst of gas which follows the expulsion of the liquid is almost explosive in character. Air can be used as a propulsive medium when gas is not available, if it is not desired to save that which accompanies the oil, but obviously gas is preferable as less likely to cause any changes in the character of oil, such as reduced gasoline content or oxidation. There is also the further danger of corrosion of fittings with air when water is present.

Work in U.S.A., Venezuela and Rumania has definitely established the fact that the gas displacement pump can more than compete with other types of pumps under certain conditions, and it is firmly believed that its use can be extended to deal with greater depths and small producers at a cost below that of deep well pumps. Miller's results are convincing for small-producing, low-level wells up to 2000 ft. deep, and from personal knowledge oil can be economically raised from much greater depths. The use of compressed gases for mechanical operations cannot be described as efficient, but nevertheless this has not prevented the general employment of compressed air for working pneumatic tools above and below ground on account of its peculiar advantages.

By a suitable combination of tubing and chamber capacity to create an oil slug of sufficient length to avoid excessive slip, say, 200 to 500 ft., yet not necessitating too high a pressure to support the column of oil in the flow tube on its displacement from the chamber, the volume of gas needed may lie between 1000 and 2000 cu. ft. per barrel. As might be expected, results vary greatly under different conditions, and there are doubtless circumstances when the system would not function properly, such as when the fluid was in a state of foam in the well, or too much floating sand accompanied the oil. Heavy viscous oils resist atomisation better than light oils, and for that reason are likely to give higher efficiencies.

It is claimed that when pressures measured by bomb are not less than 20 lb. per 100 ft., the fluid is not too light to slug ; and as regards floating sand there appears no need to worry over quantities which can be dealt with by deep well pumps. As a rule the flow pipe is so arranged that when the fluid is put in motion by admitted air, it causes a swirling action over the lower valve, thereby stirring up any deposit which might have settled from the oil in the off-time interval. A gas anchor can always be attached to the lower end of the chamber as with an ordinary deep well pump if gas interference is a factor to be considered.

Very little data is available concerning the cost of operating the displacement system, and without knowledge of all the conditions they would be meaningless. Millar gives the low figure of 3 cents per brl. extraction costs for a 1000 ft. well yielding 18 brls. of oil a day with only 15 ft. of fluid. He does not give the air input per brl. nor say what the costs include.

Assuming input gas represents an average of 2000 cu. ft. per brl., which is probably a high average for 3000 ft. wells, and that working pressures were arranged for 250 lb., a single compressor of 245 cu. ft. per min. capacity driven by a gas engine would raise 176 brls. of fluid per day. Allowing 25 per cent. depreciation on plant and charging gas at 20 cents per 1000 cu. ft. with a rate of consumption of 12 cu. ft. per h.-p. hour the power for raising the oil would be about fourpence (8 cents) per brl. This figure does not include depreciation of tubing in the well or overheads.

A considerable amount of further experimentation may be necessary before it can be said whether the process is generally applicable, but one very striking advantage can be justly claimed for the process over others for dealing with small and low fluid-level wells—namely, the automatic yet intermittent operation of wells. The working parts are so few and simple that if made of non-corrodible hard metal their life may be very long, whilst stationary equipment calls for little departure from standard

fittings. Special flush joint tubing in sizes to give close nesting will raise efficiencies, but these are refinements which are not essential but will follow improvements in other directions.

Where a supply of gas under pressure is not available, the necessary compressors can be housed in a single building, and a ring circuit main of the property can be of such size that it constitutes a reservoir for gas. The admission of gas to the wells can be regulated either by a timing device and admission valve at each well, or the former may be placed in a convenient place for electrically operating the wells in the order and for the intervals desired. According to the capacity of the wells the flows may be adjusted for periods of from five or six per hour to the same number per day, when the period of admission has been ascertained by trial. Once tuned up, the operation is automatic, and automatic pressure recorders and gas meters register what proceeds.

Once installed and tuned for each well, oil properties can be expected to run for long periods without attention beyond collecting and replacing the record cards, measuring the oil, drawing off water, and inspecting the apparatus.

Automatic Swab.

A new method has recently been introduced for lifting oil from deep wells without the use of reciprocating or rotating parts—namely, the Hughes plunger lift which operates automatically with formation gas when present in sufficient quantities. It is in reality an automatic swab which is impelled upwards in a column of specially prepared tubing by gas carrying with it a body of oil. A specially prepared column of truly reamed and flush jointed tubing free from all burrs and obstructions carries on its lower extremity a cushioned seating with admission orifice to the well, so arranged to exactly fit the extended spindle of the valve in the moving plunger. The plunger itself is a loose fitting hollow cylinder with a caged mitre valve at its base opening downwards so that when it seats in the orifice communicating with the well, the well pressure forces the valve upon its seating and then allows the gas pressure to build up under the plunger. When the pressure exceeds that due to the weight of the column of oil above the plunger, the latter is set in motion and carries upwards the overlying body of oil in the tubing.

At the surface an outflow pipe carries away the fluids which are raised, and the plunger is carried in its impetus up and beyond the outlet pipe where it traps and compresses a certain amount of oil and gas which forces the valve at its base open and so allows it to fall by gravity back into the oil and thence to the bottom of the tubing. Above the flow head and "stack" which normally

take the plunger is a valve communicating with a "surge chamber" in which the plunger can be driven and housed when it is desired to effect its withdrawal. At the end of this piping a rubber safety bumper is inserted to absorb the shock when the plunger is driven upwards. The valve can then be shut and the plunger removed at leisure. Provision is made for applying air or gas to the top of the surge chamber on reinserting the plunger in order to effect its return through the trap valve and into the working tubing. The outflow can be beaned down to any desired amount, and if necessary outside gas can be admitted to the well to supplement the natural supply. If the well is dead and static it must be started by admission of outside gas through a check valve in the tubing *via* the casing.

The apparatus is exceedingly ingenious, and its usefulness in practice will be watched with considerable interest. The particularly attractive features are the use of formation gas at low pressures to perform the work, and its automatic character. Against these have to be considered initial cost in special tubing and its wearing properties in the presence of floating sand, which is nearly always present in some quantity. It is claimed that a special plunger will deal with paraffination, but one would surmise that this system would result in a reduction of paraffin troubles owing to the nearly undisturbed character of the slug during ascent.

The consumption of gas in cubic feet per barrel is said to vary from about 125 cu. ft. for a 500 ft. lift to about 900 cu. ft. for a 4000 ft. lift of plunger.

Sundry attempts have been made to introduce rotary pumps, but without much success. No one is likely to question their suitability for some special conditions where large output and more or less stationary fluid levels are certain, but the multiple-stage turbine pump does not permit of much latitude in variations of lift and volume without loss of efficiency, and they are more expensive in first cost and their insertion and removal is a longer operation than with sucker rods. Other types of rotary pumps have been invented which would deal with high lifts and accommodate themselves more readily to changing conditions, but they failed like the turbine pumps in dealing with sandy fluids without rapid deterioration and wear. This drawback is unlikely to be overcome in the high speed rotary pump.

Paraffination of Wells.

Paraffination of wells presents one of the modern production problems never satisfactorily solved, yet it is an increasingly important subject on account of the large proportion of waxy oil which is met with in deep wells. Rumania is particularly troubled,

as all the great new fields derive their production from beds of Meotic age, which usually give highly paraffinous oils. So long as wells flow naturally no serious difficulties are usually encountered, but when artificial methods of recovery are introduced it is another matter. For that reason it seems imperative that gas pressures should be strictly controlled and re-pressuring initiated before natural flows cease. The Ceptura field of Rumania is now almost abandoned due to paraffin troubles which quickly appeared after the flush period was over, yet it is believed that vast supplies of oil remain in the sands. As the gas was never conserved or returned to the sands during the exploitation of the field and most of the wells are badly waxed, the field is likely to prove a difficult one to resuscitate, even if it proves feasible.

Few oil producers waste time on small and troublesome producing wells to-day, but in the future they will receive attention, and ways and means of operating small producers will be investigated. Natural flows are followed with gas lift, but as the fluid level falls and the discharge becomes intermittent wax troubles increase due to the more violent agitation and atomisation of the oil. The conditions are alleviated by heating the gas before admission, but this fails in course of time, and recourse is had to scrapers, steaming and other costly devices. So rapid is the precipitation of paraffin in some wells on the pump that the rods have to be pulled daily and the tubing and rods cleared of wax.

As the deposition of wax appears to be closely associated with the release of gas and light hydrocarbons which hold the solid paraffins in solution, a maintenance of pressure and avoidance of agitation would appear to offer the best prospects of avoiding trouble.

Emulsions.

Emulsions have always given considerable trouble to the production engineer and are likely to do so in the future, but their mode of origin and the many methods of breaking them down have so often been described that there is no need to discourse on this subject. It is, however, worth recording that modern systems of flowing under control through nozzles tend to encourage rather than disfavour their formation, and it may be that difficulties in this direction will increase rather than diminish as water gains access to partially depleted sands. The tendency towards the formation of emulsion when water is present is greatly aggravated by forced passage of the mixture through a confined space such as a bean, and their prevention is a matter of extreme urgency in these days when large productions have to be expeditiously handled and the crude soon finds itself in pipe stills. Considerable

pipe line and refinery troubles have resulted from the delivery of dirty crude from wells usually in the form of an emulsified product. It may not be generally known that this nuisance can be nearly always prevented by the simple expedient of passing the discharge of the well through a long inclined horizontal chamber where the contained water can drain from the oil under full well pressure before the flow nozzle is reached. It will be found that emulsions generally form where violent turbulence and pulverisation takes place, and in a controlled well the choke is obviously the first likely point. The water which collects in the separator is drawn off by a drip working continuously or intermittently.

State of Depleted Oil Sands.

To-day very little is known concerning the condition of oil reservoirs after commercial oil exhaustion or perhaps total desiccation of sands in the vicinity of wells which have ceased to produce oil. There are many reasons for believing that the depletion curve of a productive well is not always a record of desiccation of the sands, but merely a record of the increasing resistance to flow due to causes other than distance of travel. Various methods have been followed by technologists to calculate the probable ratio of extraction to oil contents, but all are based on assumptions of one kind or another, which render such estimations exceedingly questionable. Only in Hannover and Pechelbronn, Alsace, has the real condition of the sands in an exhausted oilfield been observed and measured by mining in the oil sands, and unfortunately these were shallow fields with heavy oil where the gas contents were rather high. Alsace workings did, however, prove that in that particular field only about 16·7 per cent. of the oil contents of the sand had been abstracted by wells, leaving some 83·3 per cent. for recovery by other means. By driving galleries in the sand a further 43 per cent. of the oil was obtained, and by washing the sands still more could be obtained.

The other methods of estimating the remaining contents of oil sands were :—

(*a*) Taking the average thickness and porosity of sands and calculating the contents, then comparing these with the volume extracted.

(*b*) Estimating or measuring the gas/oil ratio and assuming all that gas in excess of what would be dissolved in the oil or occurring as a liquid at the temperatures and pressures existing to have escaped from oil which remains in the sands.

(*c*) In the case of folded domal limestone fields where the oil is confined to fissures and vesicles the contents of pools may be very approximately ascertained by noting the volume of oil abstracted for each foot rise of the water table on the structures.

(*d*) Sinking new wells and coring the oil formation to make actual tests of the sands as they occur.

Only in limestone fields where the oil is under a strong hydrostatic pressure and water follows the oil, can it be fairly safely assumed that the bulk of the oil contents are removed. The strippers in these fields exhibit the coning effect around the base of the well so well that there is little cause to doubt this conclusion. By adjusting the rate of flow when the water line has approached a well, it is often possible to flow clean oil or a mixture of oil and water in any proportions until eventually water only is obtained.

Only in the Appalachian field of Bradford has methodical coring for formation been undertaken on an extensive scale in a declining and nearly moribund field to ascertain the suitability of the sand for water drive, but in many other small U.S.A. fields coring has preceded gas and water drives where profitable extraction by other methods of recovery was no longer feasible.

In the case of the Bradford field, where sheet sands of considerable regularity exist, it is estimated that from the main sand 16 to 55 ft. thick 3000 barrels per acre had been recovered prior to the use of water drive representing 13 to 15 per cent. of the oil contents. The water drive led to the extraction of a further 3000 to 7000 barrels per acre within a period of several years, compared with fifty years for the original amount. The acre foot recovery from a 36 ft. sand was raised from 90 to 128 barrels.

Very naturally geological conditions differ in nearly every oilfield, and there is an increasing tendency in deep drilling to expose a considerable thickness of sands rather than a single sand, as was previously the more general practice, due to the difficulties of controlling pressures, etc. Obviously more accurate calculations can be made to apply to sheet sands than indefinite sandy zones where the sand bodies are highly lenticular and variable in grade. Useful work on the analysis of cores has been carried out when the porosity, grain size (that retained by various sized mesh screens) and oil saturation are graphed on a depth chart. Permeability, which is really the factor that counts when dealing with water as with oil, cannot be so easily gauged as it is dependent upon many features, such as shape and orientation of grains, admixture with clayey substances, and nature of the cementation materials, etc.

There is no intention of pursuing the subject beyond remarking that there is ample evidence to show that much oil remains unrecovered in oil sands in pools developed by old methods without any particular regard for retention of pressure and little consideration for spacing and locating wells on structures; and the intention is to consider ways and means of quickly and cheaply ascertaining whether the dregs are worth serious effort at recovery and by what methods these can be most cheaply retrieved. This becomes increasingly important as wells reach greater depths, owing to the high cost of installing drilling plant to carry out any large scale operations.

Cleaning Wells.

Cleaning of wells is standing practice in some fields where detritus and sediment collects, and in time impedes or chokes the inflow of oil, and on account of these troubles pumps are either kept some distance above the sand, and where water conditions admit sumps are drilled, into which the sediment can collect. Little more has been attempted beyond treatment for wax by swabbing or washing with hot or cold oil owing to the difficulty of undertaking more drastic remedies where casing is seated and perforated pipe, liner or screen is set opposite the oil sands. Reference might, however, be made in this connection to the use of air lift for cleaning deep wells in place of tools. The value of the process has time and again been proved, and its usefulness must be appreciated by all who have had experience of air-lift work in loose sand conditions without back pressure.

The work can be accomplished by lowering a dual column of tubing to just above the accumulation of sediment. The inner 2 in. or 2½ in. pipe is kept about 100 ft. higher than the exterior 3 in. or 4 in. pipe, and arrangements are made for air to pass through the annular space between the two pipes, using the inner as the flow string. A chisel-shaped bit with large side orifices is attached to the base of the outer pipe to stir up the sediment. The whole combination is slung from the blocks in the derrick and flexible pipe connections enable the whole to be raised or lowered at will, whilst air is being admitted or a discharge is taking place. Sufficient water or oil is run into the well to create a working head within the capacity of the compressor available, and when the air reaches the point of intake the whole tubing is lowered so that the outer pipe reaches the sediment. By alternately raising and lowering the tubing whilst the air lift is in operation, the sediment is disturbed and is expelled at the surface with the fluid. The judicious repetition of this operation as an intermittent action enables the well to be cleaned in a very short time.

In many cases cleaning of wells has no beneficial results, the little sediment which collects not appreciably hindering the entrance of oil, and diminishing yields lead to reduced hours of pumping until wells can often no longer be operated at a profit.

It will often be noticed that such wells continue to yield a little oil and water so long as they are worked, but that if they are left idle for any prolonged period, they gradually dry up and no longer discharge gas. Furthermore, it will often be found that these wells will not absorb fluids and that they may often be filled with water or oil without loss into the sands. These circumstances seemed to indicate that the sands feeding a well gradually became clogged in some way and more quickly when left idle. These facts led the writer to believe that oil sands not kept submerged and bereft of all but a very little gas were becoming clogged by a precipitation of mineral salts and paraffins as a result of physical and chemical actions. As escaping gas practically always contains moisture, which on condensation to mist often makes the gas visible at the surface, it was considered that the expiring gas volumes were actually evaporating the brines mingled with the oil, thereby causing the salts previously held in solution to be precipitated in the pores of the sands or crystallized in joint cracks, cleavage planes and other channels which might previously have acted as passages for the movement of oil to the wells. Once a state of stagnation was reached, other processes came into operation which caused changes in the oil itself. The process in mind can be compared with the occasional accumulation of salt in gas wells in consequence of the evaporation of brines which gain access to the well ; and the condition of the sands was pictured as resembling the outcrop of oil sands in hot, dry countries where an incrustation of salt and a matting of asphaltic or paraffinous residues covered the surface, and other residual products clogged the pores.

Since writing the paper a very valuable contribution to the subject of permeability has appeared in the April (1932) number of the Bulletin of the American Association of Petroleum Geologists by C. M. Nevin. This writer remarks on the considerable loss of permeability which follows the passage of fluids through oil sands, and amongst the causes are mentioned :—(*a*) clogging action caused by filtering of particles from the oil and water ; (*b*) loose debris carried into the pore spaces ; (*c*) hydration and swelling of the bonding material ; (*d*) re-arrangement of the sand grains ; (*e*) unstable oil films and gummy deposits from the crude ; (*f*) possible hydrolysis of silica by water forming colloidal silica.

Under this belief ways and means were considered, firstly, for proving whether such action did take place ; secondly, for alleviating such troubles if found to exist. The virtual necessity of

keeping expenditure to an absolute minimum where results were uncertain ruled out sundry very obvious courses. If the screen or liner could be removed, the face of the sands might be reamed or scraped, but there was always an impression that the troubles might extend further than the walls of the bore and beyond the region that would be reached by reamers or scrapers. This method has been practised in some U.S.A. fields with some measure of success. Naturally the removal of a core from the body of the sand near the well would have been of great value, as the condition of the sand could be seen, but there were no suitable tools obtainable for coring horizontally in a deep bore of small diameter, and the sidetracking of the well at some depth which would enable a core of the sand to be taken near the well would be a costly operation.

It was felt that some violent process would be most likely to benefit production if the conclusions were correct, and from that point of view high explosives had first thought, but their use involved the removal or destruction of the liner, which would leave the well in bad shape for further work.

Rejuvenation with Air or Gas.

After considering many expedients it was decided to employ compressed air or gas, the idea being that by the alternate application and relief of a high gas pressure on the sands in a dry or pumped-out well, it might be possible to break away part of the surface incrustation and thereby permit some of the gas to enter the sands. It was hoped by a repetition of this performance to open gradually the pores of the sand or the old channels of movement and thereby induce a renewed movement towards the well. If the air or gas could by this means be induced to enter the sands and thereby result in some return of fluid, it was felt that there was justification for the views propounded.

During the last few years a number of experiments on these lines have been made, and in nearly every case with some tangible result. Time has never admitted of prolonged experiments, nor was the necessary plant available to carry out the work properly and check all features. Also, in nearly every case the well set aside for tests was one which had reached a stage of almost complete inactivity. Nevertheless, the results are encouraging in several widely separated fields and warrant the belief that many wells can be resuscitated in this manner. Experiments were conducted in three wells in Trinidad. In one which was quite dry the full capacity of the compressor could be forced into the well at a low pressure (80 to 85 lb.) without apparent results in the time occupied of about a week, and no difference was noticed in near-by wells.

Air was admitted to another well abandoned and dry. Pressure rose to 150 lb. and remained stationary, so that air at a rate of about 150 cu. ft. min. was entering the well. After a few hours a large cock was opened wide and the pressure suddenly released, the result being a violent outburst of air and debris followed in a few minutes by a flow and gas, which necessitated the shutting down of boiler fires. A third well seemed in an almost hopeless state for experimenting. There was no plant at the well, not even means of lowering a bailer. A plumb bob showed the well to be quite dry and there was not the slightest odour of gas. The well had given a moderate yield of oil before abandonment in a good oil sand. A cap was placed on the well and air admitted. The pressure gradually rose to 250 lb., when a big leak developed and air appeared on the outside of the casing. As the pressure rose the leak increased, and it was uncertain whether any air entered the oil sand. However, experiments were continued by raising the pressure to 150 lb. and blowing off at intervals of about half hour. After a while the air became very evil smelling at each relief, and it was clear that some had entered the sand and been expelled; by evening of the same day the well was gassing quite nicely sweet gas at a rate of several thousand cu. ft. a day. Work was then suspended for other duties, but appearances led one to suspect that the well could have been brought into production by repairing the leaky casing and continuing efforts.

Last year an experiment was undertaken in Burma with the same object in view. The production of a well 3280 ft. deep had fallen to two barrels a day obtained by pumping a few hours every second day and no improvement resulted from cleaning, replacing pump, etc. The depletion curve followed the normal course of other wells, and it has been a good producer, having yielded 250,000 barrels of oil. It was chosen for no other reason than being conveniently placed for the test and lying in what was originally prolific territory. Nothing further was done than to fit the casing head with inlet pipe from compressor with gauges on both sides of the admission valve, and an exit pipe and valves which permitted the air to be released suddenly. The pump was left in position as the 3000 ft. column of fluid in the pump tubing would more than balance pressures that would be used. In order to measure accurately the results of the work, all oil was pumped off by admitting water to the well and replacing the oil in the tubing with water. A recording gas meter was later placed on the well. Air was admitted to the well at the rate of about 120 cu. ft. per minute, and the pressure rose to 200 lb. before steadying down. Slight leaks developed in the casing, but these were not regarded as very serious. After admitting air at around 200 lb. pressure for several

hours, the well was blown off and the air gust was followed by sour gas. The operation was repeated a number of times during several days, part of the time being occupied on compressor repairs. By that time it was quite clear that the gas supply had increased considerably and when the water had been pumped from the tubing, the production of oil was found to be four barrels a day, 100 per cent. increase. The gas supply which was equally valuable was increased from 6000 to 47-50,000 cu. ft. a day or 700 per cent., equal to about seven barrels of oil. About 100,000 cu. ft. of free air is believed to have entered the sands. The sour nature of the gas for a long interval after air digestion was proof that the air had penetrated the sands for some considerable distance. The production of oil and gas was sustained and the well still yields satisfactorily.

A third experiment was very hurriedly undertaken during a brief sojurn to another old field where the production problems were particularly perplexing and erratic for reasons never adequately explained. Air was admitted to a well on the pump which had given already about 50,000 barrels of oil and was then producing only 11 barrels of oil a day with 14 barrels water. Recording gauges were fixed to note what was proceeding. The pressure rose normally to 220 lb. and then only slowly mounted higher, showing that it was entering the beds. After a first air digestion of about 55,000 cu. ft. of free air a very large flow of gas followed a brief expulsion of sour air. Several times the pressure was raised to 220 lb. and air freely entered the sands and eventually after a few days free discharge the gas volume was measured at 400,000 cu. ft. a day, an increase of over 700 per cent. The oil yield was erratic and not apparently appreciably in excess of that before, but the brief experiment proved that something very striking happened and indicated again a line of attack which might bring about important results.

Much longer periods of air or gas digestion should be given and these at a pressure which ensures admission might at times be followed by forcing benzine, crude oil or aqueous solutions into the sands after channels had been opened. The forcing of acids in the case of limestones or calcareous rocks might be useful.

The value of establishing drainage systems was recognised by old-time operators before pressure control became a general practice or indeed was feasible with the material at disposal, and to-day its value does not escape notice. The custom of permitting large initial flow after bringing in a new well is known to do more than clear the sand of drilling mud. Often big risks are run in allowing too free a flow in order to establish higher capacity, the big quantity of sand expelled proving that the sands were being broken down and channels opened to the well. The use of high explosives in

tight sands and compact limestones is a recognised oilfield practice of establishing connection between a well and oil-bearing fissures or vesicles not directly communicating with the borehole. Once communication is established an inrush of high pressure gas and oil frequently ejects fragments of rock.

Drilling at an Angle.

So capricious is the occurrence of oil in the limestone fields of Panuco, Mexico, that only a small proportion of the wells strike production which is confined to fissures. As the fissures are nearly vertical the chances of striking oil are considerably lessened by drilling vertical holes, and in consequence drilling at an angle has been successfully undertaken.

During a visit to U.S.A. a core from a Panuco well was seen where an oil-bearing fissure had been struck in a well which yielded several thousand barrels daily. The fissure was a mere crack into which a penknife blade would not enter, and the limestone was only discoloured to an insignificant depth in each side of the blackened crack, yet the yield was considerable.

The Problem of Gas Disposal.

One of the most perplexing problems connected with modern oilfield exploitation is that of disposing of surplus gas. Notwithstanding the spirited agitation against gas waste it proceeds on an enormous scale in all new fields competitively developed as more prolific, deeper wells come into production, but naturally petroleum cannot be produced without gas, and as the depth of wells increases the volume of gas held in solution likewise increases.

By working to some agreed gas-oil ratio which reasonably satisfies aspirations for a particular period in a certain field, there is less loss of gas per unit of oil abstracted than would otherwise be the case, but the large initial outputs of wells not prorated is so great that the gas volumes far exceed the markets within economic range of the fields.

Where oilfields of likely permanence lie within economic reach of markets, very large volumes of gas are piped away from the fields after being stripped of its gasoline contents, but there is usually a very great surplus for which it would be imprudent to make provision for selling on account of its lack of permanency, and this is generally destroyed by burning in open flares for safety after all local fuel and other demands have been satisfied. Although a most elaborate system of pipe lines has been installed for conducting the gas to industrial and residential centres in U.S.A., there are still incalculable volumes of gas belching into the atmosphere unused or burnt in open flares in the new great oilfields.

Repressuring.

The gas losses in Mexico between the years 1919 and 1924 and those of Persia and Venezuela in recent years, where there is no market for the gas stripped of its gasoline content, almost stagger one by their magnitude, and to-day Rumania presents a sad spectacle of gas waste. Many obvious uses for this surplus gas are known, but so few can show any acceptable return on capital which would have to be invested in plant to deal with its employment. The return of gas to the oil reservoir for repressuring is one of the numerous proposals which has been given consideration and trial, but such schemes are extremely expensive when high pressures are involved, and they necessitate unit operation of fields if the benefits are to be equitably shared. The method is being practised where a single or several companies working in close liaison control the major part of a structure, and the recycling of surplus gas after treatment for its gasoline content has proved a physical success. A noteworthy example is the Sugarland field of Texas, where the gas from flowing or gas lift wells is returned to the sands at a high pressure.

Storage of Surplus Gas.

Another project which has its attractions is the storage of surplus gas in exhausted oil or gas fields until it is wanted at a later period for field, domestic or industrial purposes. Beyond demonstrating the feasibility of recharging exhausted oil or gas formations which had not been invaded by water, little has been accomplished in this direction. The latest effort in this direction is the conservation of part of the Turner Valley oilfield gas in the old Bow Island gas field of Alberta. In 1931 about 1,500,000,000 cu. ft. of gas were so stored, and during the last winter, when an explosion at the scrubbing plant caused the partial cutting off of gas to Calgary at a time when the temperature was 20° to 30° between zero, and the town was taking a peak load of about 59,000,000 cu. ft. daily, it was necessary to draw on the Bow Island reserve supply.

Attention is being given to the forcing of gas into suitable water-charged domal structures where it could be stored under water pressure until required. On more than one occasion the proposal has been made to charge sheet sands saturated with water in convenient structures where the gas could be drawn off at high points at a later date.

Other Uses for Gas.

The manufacture of carbon black by the incomplete combustion of gas after the recovery of its gasoline content is no longer attractive, as the market is overstocked and the price is very low. Even the

extraction of gas-gasoline is unprofitable at present prices unless gas is available at a very low cost, so that there are few installations now run by independents who rely upon purchased gas.

Much research work has been undertaken with the object of finding some economic method of converting petroleum gases into other useful products, but no signal success has resulted therefrom. A limited trade is done with the products that can be liquefied at workable pressures, so that they can be sold in cylinders for use as such or for lighting in remote districts where other forms of fuel are costly.

The disposal of surplus gas from new prolific fields is always likely to be a source of difficulty, as it is only after developments have reached a very advanced stage that the potentialities can be approximately predicted, and until these can be calculated there is a natural disinclination to embark on long-distance pipe lines. Some guarantees of reasonable permanence must be obtained before finance can be found for distant distribution and the negotiation of franchises for city or public supplies can be undertaken.

Recovery of Oil Dregs.

Brief reference has already been made to the possible absence of recoverable oil dregs in fields where operated from inception in accordance with modern ideas on a unit basis. It does not require a wide stretch of imagination to picture the time when, by methodical exploitation of a suitable pool, the oil contents could be forced into a position where it would be held under a pressure between a body of gas at high points and a volume of water on the low flanks, so that oil could be drawn off at a rate which would maintain equilibrium. Many years may elapse before this ideal will be realised, although this seems to have been approximated in Persia, but the application of present-day knowledge to a normal regular structure of modest extent would go far towards reaching that goal.

The handling of dying oilfields developed by past competitive methods with little regard to conservation is the immediate anxiety of petroleum technologists, and the problem is rendered doubly difficult by the lack of reliable information. Most geologists are now prepared to admit that many of the curious anomalies shown on sub-surface contour maps do not exist, but were due to plotting data supplied by wells which had deviated from vertical. Only by a survey of many wells in a deep field could a faithful sub-surface structure map be reproduced, and this would be a costly performance.

The following processes can be applied to the recovery of the dregs of oilfields which have ceased to yield commercial quantities of oil by usual methods of extraction:—

1. Application of partial vacuum.
2. Gas drive or restoration of pressure.
3. Water drive.
4. Mining.

1. The use of vacuum has been largely superseded by re-pressuring the oil beds with gas, for whereas the use of the former can only result in a negative pressure of something under 14·7 lb. per sq. in., the latter enables positive pressures of any magnitude being applied with proportionately greater differentials. There are, however, cases where the application of a partial vacuum is the only feasible plan of improving the yield of wells on account of such features as congestion of wells and divided ownership of lands where no co-operative methods can be negotiated.

The vacuum process was very popular and widely practised when gas-gasoline fetched a high price, as it led to a greatly increased quantity of gas much richer in gasoline content even if it failed to augment the oil production considerably.

The main objections to the use of vacuum are: aspiration of air through faulty casings and fittings, the tendency to render some oils more viscous and perhaps encourage deposition of wax, the present low price of gas-gasoline, the occasional tendency for the wells to make more sand, and the difficulty of replacing pumps or cleaning wells.

2. The return of gas to the oil sands at selected spots for a partial restoration of pressure before drawing off at convenient points is regularly conducted on many nearly-exhausted oilfields and with marked success. This process suffers the disadvantage that admitted gas is liable to take paths of least resistance and to short-circuit those parts of the sand which have been least depleted by past operations. Whereas vacuum confines its attack to a body of sand in direct contact with each well to which it is applied, gas drives have to rely upon the gas finding its way to some other points where production can be taken. On this account the author has always favoured the building up of a moderate formation pressure which would ensure the charging of the oil dregs with gas before drawing off at any well. Obviously the best ultimate yields would result from re-pressuring at an early stage when the sands were flooded and an established drainage system had not been formed. This latter is a costly operation and may not always be justified.

3. Water drive has only been successfully followed on a large scale in the Bradford field of Pennsylvania and New York, and its striking success there is due to a combination of favourable circumstances. The oil-bearing sands are regular over long distances, their grain constitution is suitable for admitting and transmitting water at a rate which ensures a good expulsion of oil without short-circuiting, and the value of the oil is very high. Elsewhere the tendency has been to employ gas drives and re-pressuring schemes in preference to water.

Perhaps too little attention is being paid to water drives, and it is submitted that the use of water deserves far more consideration than it is receiving, but so many oilfield misfortunes have been attributed to water that many view its employment for such purposes with marked concern. The fact should, however, be recalled that it is to water that the concentration of oil must be ascribed in practically all great oil pools, and properly controlled and directed it might still be put to useful purpose by the production engineers. The orderly advance of edge water is advocated and carefully directed in some fields where its progress is rapid, and in the great limestone fields like Mexico some of it functions as a concentrator and driving agent.

The author has used water with very marked success on many occasions to re-establish communication with oil sands which have been isolated from wells by slides of clay, etc., although in such cases oil would have been probably more effective. But he has also witnessed many accidental water drives where oil has been carried forward as a wave ahead of a sudden intrusion of water into the oil beds.

The time element has been a major factor of original concentration, and it remains a factor of present-day schemes. Only by a slow and orderly advance can the oil be disentangled from the sands and caused to move forward.

4. Mining the oil measures has made little headway due to the great fall of oil prices. Successful operations continue at Pechelbronn, Alsace, and at Wietze, Hanover, where prices of oil are sustained by protection, but elsewhere no very successful results have been reported, although undertaken in many places. Work has been brought to an end in a number of cases by water difficulties, uncertain results, gas troubles and such like. In one case in Rumania the oil sand it was designed to strike proved to be non-productive and the shaft had to be carried to a deeper source. There are certainly many depleted oil sands which could be developed by mining owing to the absence of water in the measures and the superincumbent beds, the regularity of the oil

sands already proved by drilling and the suitability of the strata for inexpensive mining.

Modern practice inclines towards the construction of galleries in the strata below the oil sands, which latter are pierced by upward-drilled holes to drain the oil off the sand, but it is far from certain whether this method would prove satisfactory, as some sands drain so slowly that only galleries would expose sufficient surface to ensure an economic drainage of the sand.

DISCUSSION.

The President remarked that the meeting would agree that Mr. Thompson's paper was full of suggestions and most interesting, not only to those members who were interested in the subject of production, but to members generally. Such papers helped to keep all members up to date and to give them a good idea of modern developments.

He had been very interested, he said, in the lecturer's remarks about co-operation—always a favourite subject of his own. He could not help contrasting the law of offset, a hideous example of brute, unintelligent competition, with the scheme of unit development which provided an example of co-operation with intelligence, a scheme which was sure to develop in the future.

Mr. Thompson had seemed unduly alarmed at the possibility of emulsions reaching a pipe still. Naturally, emulsions were undesirable in any form of refining equipment, but the President assured the meeting from his own experience that they constituted a much more difficult problem in a cylindrical still than in a pipe still. The pipe still had, indeed, been partly developed with the object of dehydrating crude oil, and a pipe still and water vapour separator were often used in front of the main distilling unit for that purpose.

Dr. A. Wade said that the paper was a plea for unit development, which might be called co-operation, and a plaint against waste of all kinds in oil-field practice and development. With regard to unit development, or co-operation, it had been rightly shown that, although very desirable, it was fraught with tremendous difficulties. It would be quite easy if every oil-field were first of all discovered and then developed by the scientific efforts and researches of the big oil companies or interests, but the fact that a great many oil-fields—especially in places like the United States—were discovered by individual and wild-cat operators led to considerable difficulty. The speaker said that he had, for example, watched a certain field in Texas from its inception to full development. This field had been first started by a wild-cat operator

who drilled a well in the corner of a pasture. That man had drilled probably a hundred wild-cat wells in the course of his experience, and probably not more than one in twenty had given him a profitable production. In this case he had obtained quite a good well—2000 barrels or thereabouts; and this had led to a rush for the crest of the anticline and big prices were paid to the farmers for plots. A well-known operator had gone quietly down on the south-west flank and taken up fairly large acreage at a comparatively small cost per acre. On the crest there had sprung up the usual evils of town site drilling, with everyone's equipment touching his neighbour's with scarcely room to put a boiler or anything else; everybody was hastening to get down as quickly as he could. This operator drilled on his site, and his first well came in at 10,000 barrels, and in the course of a fortnight had blown in to 20,000 barrels, an output five times as large as that of the biggest well drilled on the crest. Could anybody blame an operator in his position if he was averse to joining in any scheme of co-operation which meant the sharing of his advantages with those who had paid high prices in the scramble to get in first and who had what they believed to be the best drilling sites?

The same kind of situation was bound to occur when fields were developed by many independent operators, and yet if the independents were to be preserved—and they had their uses—the moral seemed to be that some scheme must be accepted or some sort of law must be in force before development of the area in any shape or form was started.

The problem of waste was really an integral part of this idea of unit development. In the speaker's experience, the most wasteful operators in oil-fields were the independent operators and the small concerns generally. It might be said that this was by no means always the case, but his experience showed that they were usually the worst culprits. Within the last few years, in three different parts of the States, he had seen first of all a group of wells fully equipped with tanks, derricks and all apparatus standing in the middle of a producing field, and, apparently, nobody had known who owned them. In another case, on the edge of the Poindexter field, a gas-well about 3000 ft. deep had been roaring away with a noise that could be heard for over a mile; this well also had been completely equipped with tools, derrick and separators, and again the owners had disappeared. In a third case, on the edge of what had now turned out to be a very important field—the Zwolle field in Louisiana—he had seen, a few years ago, an oil-well standing in the forest, full of oil inside the casing, and outside the casing tremendous volumes of hot salt water flowing away and continuing to flow away for many months until the casing was completely

corroded. This had been going on for quite a long time, and, again, no one seemed to be responsible for the well.

In all of these cases the State was supposed to have machinery to look after that kind of occurrence, but actual experience had shown that it had not been anybody's business. The wells had been abandoned and must have caused as much damage as they were capable of causing. With unit operation an obligation would be laid upon the people who were going to agree together upon a plan of co-operation to take responsibility for abandoned wells, so that weak concerns could not endanger a whole field by simply vanishing when unable to carry on any further.

Mr. Thompson had experienced some difficulty from low-pressure sands below sands with high pressure, and the speaker suggested that this trouble had been due to occluded gas, the amount of gases involved in the oil—osmotic pressure, for instance. One oil might contain large quantities of occluded gas and another perhaps might not contain much.

The question of gas-wells which were sometimes coated with ice on the surface, such as the wells in the Turner Valley, had also been raised. The speaker thought that this phenomena could be associated with loss of temperature accompanying rapid expansion.

The speaker said that he had one or two criticisms of the paper. He did not think that all American operators of to-day would agree with Mr. Thompson that an oil-well, if left standing, would always dry up and not produce again. The Standard Oil Company of California had been conducting some experiments in that direction, and the speaker had been told recently that they had come to the conclusion that this belief was a fallacy; that they could drill wells and leave them closed in for considerable periods without any noticeable diminution in the yield. He was not putting forward this statement as actual fact, but as information he had received quite recently.

Mr. Thompson, he said, was evidently a believer in drilling small holes down to the sand. Even with the methods of drilling that had been recently developed, most operators might consider that procedure rather dangerous, especially with deep wells. It left very little margin for safety, if the operator were drilling down to the producing sand with 4 in. casing. The speaker asked how this advice agreed with the idea put forward by an American geologist recently that it was necessary to find some means of making a large chamber at the base of a well for drainage purposes. It would, perhaps, be difficult to make a chamber of this kind with a very small hole.

While in the States a couple of years ago, he had had a discussion with several American field men, and evidence had been adduced

which seemed to indicate that in certain old and abandoned fields natural re-pressuring was taking place. Fields which had been abandoned for many years had been re-examined, and it was thought that oil and gas had re-accumulated in certain favourable places in relation to the incoming waters, and that certain spots could be drilled again to give successful commercial production. If that suggestion were established as a fact, it ought to be very important, and many old and abandoned fields might be put into development again after a time.

Mr. Albert Millar said that there were several points on which he would like to touch. It would appear, he said, that to get the very best oil extraction efficiency all oil-bearing structures should be under unit control. Under such ideal conditions there would be very much less waste of materials, equipment and labour in the first place, and of the natural resources in the second. Over-production, with its attendant evils, would to a great extent be alleviated. Under unit control many of the production problems would disappear, in fact would never exist. An oil-bearing structure, when worked by a number of concerns, generally led to abnormal production problems and to troubles which sometimes baffled every effort to overcome or remedy, and it could be taken that the greater the number of companies interested the more acute the conditions became. The speaker agreed with Mr. Thompson that proration as practised to-day was certainly open to objection. It would seem that in many cases those who conscientiously practised proration had been badly hit. Unit control would make such makeshift and haphazard methods quite unnecessary.

The author had expressed himself in favour of finishing wells with small diameter holes. The speaker asked Mr. Beeby Thompson what he suggested as a definition of a small diameter ?

Drilling wells with a large finishing diameter, unless the well had to be deepened at some future date, was a waste of money ; at the same time, however, the finishing of wells with a small diameter could be carried too far, to the eventual detriment of the well. The speaker said that he, personally, preferred the finishing of a well with a production string or liner not under 6 in., preferably 7 in., but not larger than 8 in. A well should be finished with as large a hole as was economically possible, because the larger the finished hole the greater would be the face area of the sand opened up, and the rate of flow from the unit area of producing sand for a given production would be less for a hole of moderate diameter than of small diameter.

No one to-day wished to produce a well through the casing, as under such conditions control was almost, if not quite, forfeited.

The general practice was rather to bring wells in through tubing; this arrangement allowed of complete control from the outset. When wells were brought in through large diameter casing, the velocity of the flow would necessarily be low and the gas-oil ratio high. That is the reason why, before it became standard practice to "tube" a well prior to bringing it in, the flowing life of such wells was comparatively short; whereas wells finished with small diameter casing—4 to 5 in.—the velocity was higher and the gas-oil ratio lower; and the well would continue to flow much longer with a greater ultimate output. If the shoe of the tubing was set at the right depth the well could not only be brought in under perfect control but could be cleaned of all drilling mud and other sediment without the bottom of the well being subjected to any abnormal pressure differential. He believed that the sand troubles in many of the earlier drilled wells was due to producing through large diameter casing, which caused unsteady flow and periods of big pressure differential at the bottom of the hole. It was always noticeable that wells which were finished with small diameter casing into precisely the same sand conditions had a steadier flow and made very considerably less sand.

The greater the pressure differential between the sand and the hole, the greater the likelihood of sand disintegration. The speaker asked Mr. Beeby Thompson his ideas regarding the control of the pressure differential between the sand and the hole. He thought that the present practice was to keep that differential as low as possible with due regard to extraction efficiency.

The manner in which wells should be treated during the first days of production depended, he said, upon the information gathered from cores taken from the producing strata, together with previous experiences of similar conditions. Therefore the coring of the oil strata was of the utmost importance, and one could not over stress the necessity of taking cores of all oil-carrying strata.

Different types of sand required different kinds of treatment and no set rule could be laid down. The lecturer stated that the displacement pump would deal with sand in quantities that could be lifted by the ordinary plunger pump. It would probably interest members to know that there were now many instances on record of oil being produced with a percentage of sand as high as 6 to 8 per cent. by the displacement pump without any difficulty. Wells making high percentages of sand had, after many months on production, been pulled and the tubing and other parts examined, but no wear had been found.

The speaker believed that paraffination could be overcome during the flowing period by flowing the wells at the critical velocity for that type of oil being produced. For each type of paraffinous

oil there was a velocity at which it could be flowed without precipitation of the paraffin in the tubing. Again, there was no set rule, and each well and each type of well had to be taken and studied by itself. When the flowing period of a well was passed it could be still further produced, without paraffination, by using the displacement pumping method of raising oil.

Mr. T. R. H. Garrett remarked that all the speakers seemed to be in agreement with the remarks about unit operation. When speaking of drilling into the oil-sand with a hole of as small a diameter as possible, the lecturer probably had in mind, in addition to the other matters mentioned, the great trouble that has been experienced in drilling into weak sands with a large hole ; frequently, after some period of production, a cavity is formed into which the next bed over the sand collapses and seals off the oil-sand from the casing. The speaker said that he had seen this happen several times.

The lecturer made the rather sweeping statement that the pressure was mainly a function of the depth. Later on in the paper that statement was somewhat toned down, but the speaker thought that it was not correct in a large number of fields. For instance, in the Sanga Sanga field of East Borneo one well at a depth of 880 ft. had a gas-pressure many times greater than that encountered in much deeper wells, and much greater than in wells higher or lower on the structure. Surely the pressure is mainly a function of the amount of gas.

The lecturer had suggested that the pore space in the sands might be expected to be less the deeper one went. Surely, the speaker was not referring to limestones or any peculiarly porous bed, but to sandstones—the majority of the grains were quartz, which was almost incompressible. If those quartz grains were perfect spheres of equal size, no matter what their size was, the pore space would be exactly the same. We knew that they were not equal perfect spheres, but if they were angular and had smaller pieces amongst them, they would be jumbled up during the deposition, and after they had had a pressure of 500 ft. of beds on them, those that could be pushed over and go into a smaller space would have been pushed over, and even if the pressure was increased by a further 5,000 or 10,000 ft. of beds over them, not much more re-arrangement would take place. The subsequent folding of the beds would have much more effect. The speaker said that he could not see, therefore, why the pore space should be decreased appreciably by depth.

Dr. F. H. Garner remarked that he had been interested in the statement with regard to the formation of ice on the outside

of the well. It seemed that the possible cause of this phenomenon was the proportion of the easily condensable hydrocarbons such as propane, butane or isobutane in the gas, of which the latent heat of vaporisation with release of pressure was responsible for the drop in temperature. It was possible that different proportions of these hydrocarbons occurred in the gases from the fields mentioned and accounted for the difference in behaviour. In order to settle the question it would be necessary to have definite information about the composition of the gas, and about the pressure drop at the casing head.

Mr. C. Dabell said that to him the question arose as to whether the paper should not be accepted as particularly applicable to the present bad times of the petroleum industry. If that was so, then the author had put up a very strong case for unit operation or co-operation. The same consideration might apply also to the question of drilling deep wells of a small diameter. The first consideration in these times in connection with production must be cost. Therefore, the smaller the diameter, within reason, the better. If the large diameter casings were eliminated, the company concerned would be well on the way, with the saving on the original well, to drill a second one if necessary. Whilst at that point, the speaker said that he would recommend that whenever a concern decided to drill a deep test, they should give serious thought to drilling a second one, simultaneously, for in so many cases the first test went wrong in some manner or another.

On the subject of the bottom hole choke, the speaker said that he was reminded of the fact that in Rumania, prior to and during the war, certain producers had been having great trouble with some of their biggest producing wells, which would flow properly for a certain period and then sand-up for a week or two. When the Germans had come over the frontier, a certain group had devoted themselves to destroying everything, and had naturally given their best attention to these large wells; they had thrown all sorts of material into them. The result had been that when the Germans arrived at the field the wells continued to flow without any sand trouble for the whole of the time the invaders had been there.

Mr. R. J. Ward considered that the lecturer should be complimented, particularly on his remarks concerning the action of the Province of Alberta in shutting down all their producers on account of the waste of gas. As the lecturer had rightly pointed out, it would be much kinder to those who had been pioneers in producing if the Government had taken steps to prove whether or no there was production below the limestone before taking such action.

The measure had become very hard on those who had been pioneers in the field ; they had got their staff and their production, and had been suddenly stopped from working. Regarding paraffination and the question of recovery from sands, the speaker thought that if and when times returned when it would be possible to produce other than by flowing—when the price would make it worth while —it occurred to him that possibly the " Frasch " method of production as practised by the sulphur producers in Texas might be of some assistance. Wells are drilled to the sulphur, finishing with 6-in. casing ; 3-in. tubing is lowered, inside of which a string of 1-in. tubing is inserted. Superheated water at about 100 lb./sq. in. pressure (335° F.) is pumped down between the 6-in. casing and outside of 3-in. tubing. This melts the sulphur, which is lifted by compressed air ; air of about 500 lb. pressure is introduced via the 1-in. pipe, the melted sulphur and water being raised through the 3-in. pipe to the surface, when it is run into large rectangular vats.

The speaker considered that by keeping this constant pressure going and by the heat introduced at bottom of the well, part of the paraffination might be done away with and gas, and also production, brought back. He merely suggested that it might be possible to apply this method in fields in which production had fallen very badly.

Captain D. Comins said that he wished to raise a few points which seemed to him to be doubtful. For instance, the lecturer had said : " Evidence points to the fact that much more gas is present in oil measures than could be absorbed by the oil contents." The speaker said that in his opinion there was far less free gas directly associated with the crude in virgin fields than was generally believed to be the case. The physical conditions in a virgin field were that during geological time the whole system had got into equilibrium.

If there was any surplus gas which could not be dissolved in the crude under the pressure and temperature conditions obtaining, it found its way to the top of the structure. Very rapidly after starting production, especially in tight reservoirs, this equilibrium was disturbed, and pressures were lowered locally substantially below the saturation pressure of the crude. The result was that gas was evolved from solution in the reservoir and only part of this gas was produced in the wells. After only a few weeks' production a considerable amount of free gas would thereby be associated with the crude, and it was this process, the speaker contended, which gave rise to the general impression that there was always a surplus of gas in the oil measures.

In open reservoir rocks, especially in fields under unit operation, the process described only applied to a limited extent, and even after many years production it was still possible for producing gas-oil ratios of wells to approximate to the dissolved gas content of the crude under the pressure and temperature conditions obtaining.

The lecturer had suggested that edge water was an important potential source of energy in a reservoir, as containing gas in solution which was liberated as reservoir pressures declined. The speaker submitted that this could only be so in a comparatively unimportant degree. On purely theoretical grounds, and also in his own experience, edge water even under high pressures could only contain a comparatively negligible amount of gas in solution.

He had often carried out experiments in which water had been in contact with gas-saturated crude under high pressure, but had hardly dissolved any gas to speak of. He had worked on a well which, when flowing, produced about 4 million cu. ft. gas a day, about 300,000 gallons water and a little oil. The impression received on seeing such a well flowing was that there was a great deal of gas in solution in the water, but there was not. After closing the well in and bleeding off the gas which separated out, the water at surface, even although under the high pressure of 840 lb./sq. in., was absolutely dead and contained practically no gas in solution. On opening the valve slightly, the water flopped out quite non-aerated as if from a bathroom tap. He also knew of a number of edge water wells that had no gas. In such wells only a negligible puff of gas would collect when they were closed in after bailing down.

The theoretical and physical case against edge water containing more than a small amount of gas in solution was that free gas in equilibrium with oil at high pressures was mostly methane and ethane, and these gases were only slightly soluble in water.

H_2S was very soluble, but the H_2S content of gas in equilibrium with oil at high pressures was low. As each gas would only dissolve in the edge water in proportion to its partial pressure in the free gas, the amount of H_2S which could dissolve in the edge water was also low.

As an illustration, consider a known specific case of a reservoir with reservoir temperature near oil-water level 40° C., pressure of the free gas 30 atmospheres, and constitution of the free gas 3·5 per cent. H_2S, 74 per cent. methane, 18 per cent. ethane, remainder heavier hydrocarbons.

The partial pressures of these gases were therefore for H_2S 1·0 atmosphere, methane 22·2 atmospheres, ethane 5·4 atmospheres.

Now at 40° C. the solubility of H_2S in fresh water was about 1·7 volumes per atmosphere, of methane about 0·024 and of ethane about 0·030.* The amounts of these gases in solution per unit volume water worked out therefore H_2S 1·7 × 1·0 = 1·70 volumes; methane 0·024 × 22·2 = 0·53 volumes, ethane 0·030 × 5·4 = 0·16 volumes.

The total gas in solution in the water would therefore only amount to 2·4 volumes per unit volume. In the particular instance to which the speaker was referring the total gas in solution in the crude was about 40 volumes per unit volume, and he submitted that on these figures the gas in solution in the edge water was comparatively negligible as a source of potential energy. In practice the amount of gas dissolved in the edge water would be even less than the calculated figure of 2·4 volumes, as gases are known to be less soluble in salt water than in fresh water. The speaker did not know of any solubility figures for these gases in salt water, but the point could easily be settled experimentally by running a high pressure bottom hole sample taker into closed in edge water wells.

The lecturer was speculating upon what would be the effect of the modern method of flowing wells with high back pressure and therefore lower bottom hole differential pressures. In tight reservoirs the smaller difference between the producing bottom hole pressures of wells and the saturation pressure of the crude in the drainage zones results in decreased producing gas/oil ratios. This in turn should result in increased ultimate recovery from the reservoir as more gas is retained in the crude.

In very open reservoirs back pressure control had little if any effect on gas/oil ratios.

In questioning whether back pressure control was being carried too far, the lecturer had used the metaphor of a leaky sodawater syphon as an illustration that gas could be used inefficiently. The speaker recognised that it was not always fair to attack a metaphor, but surely in the case of a leaky syphon the leak was from what corresponded to the gas dome in the reservoir and not from the spout which corresponds to a producing well ?

The lecturer had referred to wells in Rumania in the crestal part of structures which had gradually developed increased gas/oil ratios and finally gone to gas. This the speaker contended was a perfectly normal process in fields developed by unit operation and should not be considered as a technical objection to back pressure control of wells. It merely indicated that the gas which would otherwise have been wastefully produced by the crestal

* (These solubility figures are converted from the authoritative data contained in the International Critical Tables, Vol. III.)

wells had been conserved in the reservoir and had accumulated in the gas dome. No doubt on fields where no agreements regarding unit operation existed between leaseholders on the crest and down the flanks, complications might arise, but that was a commercial and legal point rather than a technical one.

The speaker entirely agreed with the lecturer, however, in the suggestion that, in some cases, back pressure control might result in adequate drainage channels not being formed. For that reason it was an advantage on some fields to have a short period of heavy flow when a well first came in in order to create channels and then to proceed to the modern method of restricted flow.

Referring to the deep oil fields being developed by modern drilling methods, the lecturer had said that, apart from the increased pressures and consequently greater dissolved gas content, these should have much the same characteristics as shallower fields. In the speaker's opinion the percentage recovery from these deep fields should be greater than from shallower ones. Owing not only to the higher gas content, but also to the higher temperatures, the gravity, viscosity and surface tension of deep field crudes would, in the actual reservoir, be less than that of similar crude in shallow fields. Moreover, as a general rule the initial closed in pressures of wells in deep structures were greater than those of wells in shallow structures. There was therefore proportionately a greater supply of energy available for producing the crude, provided pressures were not dissipated by wasteful methods such as production from crestal wells or unrestricted flow from wells in tight reservoir rocks.

The speaker considered that the flowing temperature of a well was a normal function of the reservoir temperature, the producing gas/oil ratio, the pressure drop, the capacity of the well and the rate of flow. By varying the back pressure and the position of the bean of a high pressure high gas/oil ratio well wide variations in flowing temperatures could be controlled.

Referring to points raised by other speakers, Dr. Wade had mentioned a case of natural repressuring having occurred in a field which was shut down for a considerable period. A possible explanation might be that, owing to poor connection with the water table, there was only a partially competent hydrostatic drive. In other words, the field when shut down was not in static equilibrium with the water table. The re-establishment of such equilibrium might take tens or even hundreds of years. In the speaker's opinion future generations would be able profitably to re-open a number of abandoned fields. In such fields oil-water level would be found at a much higher elevation than the elevation when the field was shut down, but the oil above the water would have substantially regained pressure. It was an easy matter to ascertain on which

fields natural repressuring might take place. They were the fields in which the pressures or levels of edge water wells had not remained constant, but had dropped at a lesser rate than the static pressures of oil wells. Such conditions indicated a partially competent hydrostatic drive.

Mr. Millar had mentioned that there was a critical production for each well at which it might be possible to avoid deposition of paraffin. Possibly the explanation was that this production represented the exact back pressure at which the flowing temperature in the casing was at all points maintained above the temperature of crystallisation of the wax for the particular crude. This would therefore not be possible on all fields.

Mr. Garrett had mentioned a special case of a shallow well having a higher pressure than deeper wells on the same structure and had used this as an argument against the usually accepted generalisation that deep fields have higher reservoir pressures than shallow fields. The speaker did not know the facts of this case, but wondered whether the shallow well mentioned was on the crestal gas zone of the structure, which, if so, would, of course, account for the higher closed in pressure.

Mr. Beeby Thompson, in reply, said that Mr. Kewley had referred to the fact that emulsions in pipe stills would not themselves cause trouble. The lecturer said that what he really had in mind was the dirt that emulsions carried with them. He agreed that a simple emulsion was not a serious matter. He recalled a case in Rumania recently where oil purchased from outside companies for distillation in pipe stills caused serious trouble through suspended dirt in emulsions.

Perhaps the chief of the interesting questions to which Dr. Wade had referred was the drying up of oil wells. The lecturer desired to make it clear that oil wells did not dry up unless they had a very low static level on abandonment. He agreed that wells shut in during their flush period and even when still capable of a fair yield did not usually suffer seriously from a shut down, if it was general in the field. In former days, when a value had been attached to wells giving a few barrels a day, it had been usual to pump them dry and be quite satisfied if the fluid only rose perhaps 10 to 15 feet. Nowadays, such wells were of little interest to producers. He attributed the process of desiccation to evaporation by gas of the stagnant fluid that was left in the well. By the methods described he had been able to obtain a return of fluid.

The same speaker had referred to the danger of drilling small holes. He had hoped someone with wide drilling experience would

express his views on that proposal. Small-hole drillings appeared to be attracting more general attention. Although many argued that small diameter wells could not be safely drilled because it was impossible to keep sufficient mud in the hole to hold the pressure down, several excellent rigs of the mining type were actually in use to-day and a great saving of time and expense was effected.

Mr. Millar had asked what was considered to be a small diameter. He replied that he had in view a diameter of 3½–4½ inches, which was quite possible with the new types of hydraulic feed drill. Mr. Millar had also referred to the taking of horizontal cores. The lecturer said that with the help of two of his colleagues, Mr. Jennings and Mr. J. Romanes, he had devised an apparatus for coring horizontally in deep wells. The apparatus was not perfected at the moment, but had reached a stage at which it was possible to produce excellent cores. The lecturer exhibited samples of cores taken through the casing and the cement, and said that he hoped that they would be able to take out some very good cores of oil-sand at considerable depths. In small diameter wells it was naturally very difficult to get a long core, but with an 8-inch diameter hole it should be possible to get cores of 6 in. or more in length.

Mr. Millar had referred to paraffination in the displacement pump wells. He thought that the requisite degree of cooling to cause precipitation was the direct result of a critical velocity being reached. Recently in Rumania a very paraffinous well had functioned perfectly for months without trouble, but desiring more oil the owners had lowered the pump a little deeper to get an additional head, with the result that paraffination had set in immediately. This experience showed that a great deal of care had to be exercised in order to get the correct adjustment of flow.

Mr. Garrett had referred to higher pressures in upper oil measures than those deeper in Borneo. He had been generalising when he said that pressure was a function of depth. Until a few years ago it had been more or less agreed that this was so, and many figures had been collected by American technologists of pressures at different depths. Authoritative tables had been given in U.S.A. technical publications showing that there was a more or less regular increase with depth to depths attained in those days. It was now known, however, that very erratic pressures were found at greater depths. The lecturer was inclined to doubt the accuracy of reported high pressures at shallow depths, unless they were actually measured pressures. In the spectacular gushes, when wells had been flowing from ten to fifteen thousand tons a day with perhaps 100,000,000 cubic feet of gas, technologists formed the opinion that they had

had enormous pressures to contend with. He did not think that the pressures were nearly so high as suspected. Such large volumes of fluid had to be dealt with, coupled with such tremendous amounts of sand, that pressures were very deceptive. Mr. Garrett asked the lecturer upon what evidence he based his statement that the density of rocks increased at depths. As the depth increased the rocks were usually more compacted, and changes of some kind were rather to be expected. Many forms of change were possible, and metamorphosism arose from a variety of causes. Heat might not be a cause, but pressure, recrystallisation and other actions were more likely factors. In one field known to him, where measurements of density had been methodically taken, there was a regular increase of density of rocks with depth.

He thanked Dr. Garner for his suggestion, which seemed a very reasonable one, and afforded an explanation for some of the frosting anomalies which had puzzled him for some time. Mr. Dabell's reference to the German handling of the wells in Rumania during the war afforded an interesting example of how involuntary obstructions had checked cavings and undoubtedly caused sustained yields. Mr. Ward had, of course, been referring to the Calcasieu sulphur field of Texas, where the Frasch method was first introduced. It was also, the lecturer believed, in use in other Gulf Coast dome fields, but he doubted whether it could be applied to oil.

The lecturer considered that Capt. Comins was in error in questioning the amount of gas that could be dissolved in water. He had no figures with him concerning the solution of gases at different temperatures, but he believed that ordinary water would dissolve about 3·7 per cent. of methane at normal temperature and pressure, which, of course, would be a good deal less at the high temperatures which occurred in the earth. The lecturer felt convinced that the speaker was wrong in believing that water did not absorb certain oilfield gases very freely. When carrying water during drilling operations in oil measures it was a common occurrence when bailing from the bottom for the water to be saturated with gas. He had seen this occur innumerable times, and it was, indeed, a general feature in many fields. He knew that CO_2 was often present, and its high solubility in water was known. H_2S was also very soluble. He was sure that these waters were not all very heavily charged with H_2S as there was no pronounced odour. In Mexico, round the Dos Bocas well, all vegetation had been killed for miles, due to the occurrence of H_2S in the gas which escaped with the water. He thought the edge waters of some oilfields contained a considerable amount of gas in solution.

He had omitted to mention the other contributory factors besides pressure which combined to increase the recovery ratio of oil-sands under pressure control, but they naturally had a very important influence. The speaker had referred to the lecturer's metaphor of the soda-water syphon. He thought that the speaker's interpretation of that metaphor was due to a misapprehension. The gas zone of an oil pool is equivalent to the gas accumulation at the top of the vessel, and the liquid represents the contents of the reservoir. The leakage to which reference was made was from the syphon tube, yet it was sufficient to drain off the gas without causing any discharge of fluid.

The meeting passed a hearty vote of thanks to the lecturer.

The following written contributions to the discussion were subsequently received :

From **Mr. S. H. Chapman :**

Regarding proration, it always seems to me that the case for the small producer is not always appreciated as it should be by the larger companies. How much oil has a man the right to take out of his discovery well ? In other words, to what extent should he be allowed to benefit by the special risk he has taken in drilling the well ? It would seem to be a very unfair law to confine the discoverer to a greatly curtailed production without giving him the right to take up more land around the discovery well, as was actually provided for in the late Imperial Russian Petroleum Laws and also in mining by the old Spanish Mining Laws.

The next point in Mr. Beeby Thompson's paper that I would like to touch upon is proper control in bringing in " wild cats."

Since taking and testing of cores has become common practice, and again the practice of testing a "sand" by means of a flow-tester through the drill stem makes the putting in, for that special purpose, of a string of casing unnecessary, it is nearly impossible to pass undetected an oil-bearing stratum.

Again, now that by means of outside flush drill-pipe rotating through a stuffing-box with hydraulic control for snubbing in and taking out drill pipe under pressure, to include perhaps a safety joint near the top of the drill pipe to allow for unscrewing, if necessary, just below the control gate valve so that the latter can be closed, it seems to me that there is absolutely nothing against, and everything for, drilling the first test or two in virgin territory with the rotary.

For subsequent wells, provided the pressure has been found to be comparatively low, let us say not more than 500 lb. closed in pressure (i.e., rock pressure minus a full head of oil in the well),

it is a moot point if such wells would not be better drilled in with cable tools in the old Mexican fashion, i.e. by letting them blow for a few minutes in order to open up channels into the well. This, of course, should only apply to limestones or non-caving sandstone fields.

In fields where the oil is in loose sands, the soundest method appears to be to core wherever oil is suspected and if the oil is tightly mudded-off, an easy and quick method is to bring it in by circulating water and high-pressure gas (if available).

In reducing output, the main controlling factor should be a predetermined percentage allowance of the bottom-hole-pressure-drop rather than a percentage of a so-called potential production.

With regard to Mr. Beeby Thompson's reference to edge or bottom waters being " heavily charged with gas as at Dos Boscas " and in Russia " the intermediate waters saturated with gass," I can only suppose that he is referring to gas and water being produced concurrently, as, for example, in an air-lift for raising water. Certainly the amount of petroleum gas that can be absorbed in water is, as Captain Comins has stated, infinitesimal.

Dr. Shaw has informed me that in West Virginia gases occur with water, but that it is supposed that the gas is only passing through the water. However, Mr. Beeby Thompson will surely explain exactly what he means by this apparently impossible condition.

Far from being detrimental to an oilfield, it seems that edge or bottom water, although a bad master, is an excellent servant, and that making use of a water-drive is probably the most efficient method for raising oil to the surface, always provided that the oil/water level is kept even.

Again, unevenness of a water-drive may, from time to time, be corrected, at any rate, in limestone, by reducing or cutting off entirely the production for a few weeks in the area where the water has coned up. I think in Mexico it took from three to six weeks. Water is, of course, nowadays controlled to a large extent and to a very accurate degree by multiple beans.

Mr. Beeby Thompson's remarks as to the overcoming of emulsion by running oil and water through a separator at the surface with the pressure still on and taking off the oil and gas from the top and the water from the bottom is now, I believe, common practice where there is a danger of producing emulsive oil.

Mr. Beeby Thompson is apparently an enthusiast for the use of bottom-hole beans. Personally, except where they are used to overcome inconvenient freezing at the surface, caused by the great reduction in pressure, as occurs in the Turner Valley, I cannot see what use they are ; because, surely, the easiest and most convenient

place to control the flow is at the surface valve, and in this connection, as regards gas/oil ratios, it is not apparent how a gas/oil ratio can be modified by any other means than by regulating the bottom hole differential, that is, the flow into the well controlled by the surface-valve.

Provided the tubing or casing is a suitable size to take the production, surely no change in diameters can alter the gas/oil ratio after the oil is once inside the casing.

I think all are in agreement with Mr. Beeby Thompson regarding preference for small diameters for drilling. Both for easy control and low costs no one would wish to drill in a larger hole than 10 in. for 8 in. casing, but unfortunately we cannot normally reach depths of 6000 or 8000 feet unless we begin the hole with considerably larger diameters, especially if it is necessary to isolate water from the pay. But this is not the whole story, as Mr. Thompson himself shows in his paper, because the greater the diameter (i.e. exposed surface in the pay) the easier will the oil flow into the well.

In the early days in Baku the company for which I worked had 3 to 4 in. air lifts in one well. This well had 20 in. casing down to the pay. With increasing encroachment of water all over the field, we would have been very pleased to have used air-lifts of this capacity in several other wells, but were unable to do so owing to the diameters being too small.

After a well has ceased to flow, 6⅝ in. is a good size to end up with as, with a 4 in. rising main and using the annular space for air or gas injection, provided, of course, the oil is there, a production of five to six thousand barrels can be maintained. One realises that for small producers with high pressures and tight sands a 3 in. or 2 in. diameter is large enough for producing through, but the exposed area of the sand is very much smaller than one would like it to be.

After hearing Mr. Thompson's reference to the possibilities of increasing production by heat, I cannot refrain from mentioning the results of an unfortunate experiment I was told to make many years ago in Mexico. A small well of asphaltic base ceased to produce. It was suggested that the limestone was gummed up with asphalt. As this well was only a few hundred feet deep I circulated steam with the intention of removing the asphalt from the limestone walls. The result of this experiment was to bring into the well, not oil but about 100 feet of free sulphur which set as hard as cement and for a time at any rate plugged the hole with the tubing also firmly "cemented" into the casing.

Mr. Thompson refers to irrational spacing of wells. The wasteful absurdity of a forest of derricks on town plots is, perhaps, what

strikes the British oil operative on his first visit to U.S.A. fields. But apart from these absurdities, rational and economical spacing, if not the whole art of economical production, is one of its most important functions and, it seems to me, should be worked out during the field's early activity. Certainly, we can learn much from the obituary notice of a dead or even senile field, but we can obtain much more useful data from the incipient producing field itself, where the knowledge gained is to be put to use. It is local conditions that count.

To give a few, we should try to find out if there is a strong water drive or not and, if so, place the well locations away from the water; indeed, if the water is strong enough to make gas energy unnecessary as it was in "The Golden Lane," on the very crest itself. We may find the opposite; no rising water, but an increasing gas field with falling oil-level, making wells near the oil/water level preferable.

The idiosyncrasies of limestone fields are perhaps less understood than those of sand fields, chiefly, I suppose, on account of their comparative rarity. At any rate, oil men usually think in terms of sand, as a candid friend once said to me, when disagreeing in a discussion on a limestone field, "Your head is full of sand."

But all limestone fields are not alike and behave differently in their flow into wells.

We have the so-called Caprock limestone type—I refer to the extremely cavernous dolomitic limestones overlying the salt plugs in the Gulf fields that give such unimpeded flow, very high recovery and short life.

Then we have the massive limestones with their varying porosity and permeability in depth as well as length and again combinations and variations of porous and jointed rocks, and a third type, as in the Panuco field, of impervious limestone containing oil only in cracks and crevices.

All these types must affect differently the flow through the rock into the wells and so the economical spacing of wells.

From **Mr. A. J. Goodman.**—Mr. Beeby Thompson asks for explanations of some of the anomalies connected with the freezing of wells and mentions Turner Valley in particular. Possibly a paper by W. P. Campbell, which appears in the Transactions of the Canadian Institute of Mining and Metallurgy for 1930, p. 434, may give the needed information.

Campbell points out that the "slugs" of so called "carbon" consist of a mixture of dolomitic limestone and silica, presumably from the Palæozoic limestone producing horizon, together with iron sulphide scale (from the casing). The whole mass is bound

together with ice and is porous, with hydrogen sulphide occurring in the pores. No solidified hydrocarbons have been detected except small quantities of paraffin-wax. The ice is believed to come from the drilling water which has seeped through joints in the casing, and he presumes the immediate cause of freezing inside the well is caused by the differential pressures which occur where the diameter of the casing is reduced by the accumulation of limestone debris. The application of back pressure on the well suggested as a remedy for freezing by Campbell, although at first received rather sceptically, is now recognised as the proper remedy. Incidentally compulsory conservation measures have rendered the application of back-pressure on the wells a necessity in most cases.

From **Mr. C. E. Capito.**—Mr. Capito would like to have a definition of a small hole, and whether the author considers a 6⅝ in. or 7 in. oil string a small hole or whether he wishes to reduce his oil string still more. He would like to know whether the use of larger oil strings, say 8¼ in. and upwards, and taking production through tubing would not be equally good as far as the production and flowing life of a well is concerned.

Does the author think that his more prolonged and greater total flow of oil from a smaller oil string is due to giving the well a longer life owing to having a smaller pressure differential on the oil sand and thus conserving gas to bring more oil to the well? A larger oil string, especially if used without tubing, would tend to give a much larger gas/oil ratio as well as reducing the velocities in the oil string causing the gas to slip past the oil.

If this is not true, how is it that the insertion of tubing with or without a bean at the surface or on the bottom of the tubing more often than not retards the decline curve of a well and eventually gives a larger ultimate yield, even though the insertion of such tubing or the beaning back of a well does give an immediate small drop in production?

If the oil string is too small, only the cream of the production can be obtained, as little room is left to get a reserve of oil for a deep well pump and no room for the chamber of a displacement pump. A small oil string is more likely to get bent or damaged than a larger one and thus prevent a pump from entering it.

To get at the best method of developing a field it would be interesting to get hold of figures showing the production of wells, handled properly, showing the total ultimate production of a well deepened in stages, each oilsand being produced to its commercial limit, and that of a well which takes all the oilsands together and produces them collectively until commercially depleted. Neither

type of well should be affected by offsets, as such would, of course, materially affect the result in either case.

Can the author produce figures which show that the more violent production methods of the past have produced greater ultimate quantity of oil per well than the more gentle methods of the present day ?

Might not the trouble in Rumania of wells going over to gas be due to the roof falling in on the top of the oil strata, blocking a lot of this off and allowing only a small passage for the gas to come through ?

Mr. A. Beeby Thompson, in a written reply, states : Concerning the several references to the diminished face of oil strata exposed to a borehole in the case of small diameter holes, it is contended that this is of relatively small importance where high pressures are involved. Under old practice, when the final yields of wells were derived from gravity seepage, it is agreed that the enlargement of the hole or the formation of a larger sump in the sand is undoubtedly an advantage, and the attempts to produce such chambers were fully justified ; but under modern, controlled, high-pressure flow it is usual to expose a much greater thickness of oil measures than was formerly possible, and this should more than compensate for larger holes in single sands. In addition it is hoped and believed that all the useful contents of the sands will be expelled during the flow period of the wells. Under such conditions the diameter of hole is immaterial from a productive point of view, more particularly as such a small proportion of the actual capacity of the well is allowed to flow to keep the gas/oil ratio within bounds. With high pressures large productions can result from very small cracks or pores, as we know from the yields of wells in fissured limestones.

Mr. Garrett's reference to the dangers of caving in large diameter holes is very pertinent to the subject. It is, and has been, a most serious source of trouble to production engineers.

Dr. Wade and Capt. Comins referred to the possible re-concentration of oil in an abandoned oilfield. This view is entirely in accordance with personal views based on observations. Given the requisite time and the abandonment of the field in a suitable condition to prevent loss of gas and dissipation of waters, readjustments of equilibrium would result in a new concentration of oil into " highs " with much smaller dimensions than in the original pool.

Dealing in more detail with Mr. Millar's remarks with reference to small finishing diameter of wells, the author had in mind the completion of wells in such a state that no deepening would be undertaken. Modern practice is tending towards the exposure

of a number of horizons rather than the development of sand after sand in succession, unless pressures or water conditions impose insuperable obstacles. Then, again, it is anticipated that controlled flow will so extend the life of wells that it will generally be unprofitable to await the economic exhaustion of one horizon before tapping a deeper one when they are too far apart for joint production.

Sand troubles of the past were unquestionably aggravated by the intermittent ejections caused by unchecked flow, so that steady production very largely removes sand influxes. The smaller the bottom hole differential pressure, the lower as a rule the gas-oil ratio, but this is not invariably the case.

Capt. Comins' remarks cover such a wide and interesting field that it is difficult to reply adequately in a brief way. Although unable to give definite figures, the author maintains his view that the gas in most oilfields far exceeds that held in solution by the oil. Conditions force one to admit that there is no excess of gas in some fields, but this could hardly apply to those pools where large gas zones overlie the oil or where widespread horizons have yielded gas only even far down on the flanks. Such separated gas could not exercise any of its functions in connection with expulsion phenomena if there were sufficient gas dissolved in the oil to ensure the latter's total expulsion under controlled flow and unified operation. This ideal has never been achieved hitherto in any oilfield because modern ideas were not applied to pools before wasteful production methods had been employed. As we must still content ourselves with wasteful methods in the majority of fields competitively developed, it is suggested that these surplus gas supplies justify the care that is usually taken for their preservation, for it is almost impossible to believe that the high pressure gas would not find its way into the oil sands as the pressure on the pool fell, and so replace to some extent the dissolved gas wasted as the result of competitive development or hasty production.

Regarding the solution of oilfield gases in waters it is impossible to combat the figures given, but they do not assist in explaining the anomalies which undoubtedly exist. It is readily admitted that in the quoted case of Mexico the gas may not exist in solution, and its escape in a free state may partly account for the flow of wells, but all those associated with widespread oilfield operations are acquainted with the phenomena of the contents of bailers being expelled by escaping gas on raising rapidly from deep wells when water is being carried in oil measures. A well which has penetrated oil sands and is standing full of water will often be perfectly dormant when untouched, there will be no ebullition, froth on surface or effervescence, yet when a filled bailer is withdrawn

from the bottom of the hole, almost its entire liquid contents will be violently expelled, proving that the gas was in solution. A pressure bailer with small relief valve to permit the release of a dangerous pressure can be raised with the fluid intact.

This is such a common phenomena that it affords conclusive evidence that much gas is dissolved in water, and results so inconsistent with theoretical deductions would appear to be associated with differential solution. May it not be possible that, just as certain products predominate in the gases evolved from wells at different stages of their history, a single gas may be selectively absorbed by water rather than a mixture, thus eliminating the question of partial pressures ? As the gas released in such cases is often inodorous, and in consequence liable to mislead one regarding its connection with oil, it may possibly be CO_2 or CH_4 only.

There is not the slightest intention of dogmatising on such a subject, and it was purposely introduced to encourage discussion, especially as available data bearing on the solubility of oilfield gases in oils and waters of variable character is meagre, contradictory and inconclusive.

The author is in entire agreement with Capt. Comins regarding the higher ultimate percentage abstraction of oil from the deeper oil sources, but the point he wished to make was that the sands probably contain less oil than those of equal thickness and extent at shallow depth.

Mr. Stanley Chapman's reference to the use of a sand tester is interesting, for many view with misgivings their insertion in a well. If made generally applicable, an important tool can be added to the list of those which are assisting the production engineer. Controlled edge or bottom water can be, as Mr. Chapman says, a useful servant, if judiciously directed in oilfield development. As a rule the water advances at a much slower rate than the exhaustion of hydrocarbons proceeds.

Mr. Chapman's criticism of the use of bottom-hole beans is, in the author's view, unjustified, for apart from the temperature regulation it makes possible means are afforded for controlling pressure differentials close to the source instead of a mile or more away where other factors introduce complications. Whilst unwilling to concede all the claims made for bottom-hole chokes, many seem reasonable. No production engineer of experience has failed to experience the difficulty of inducing flows in tubing even when the pressure conditions were favourable. Once a flow is started by adjustment of the depth of flow pipe, swabbing, surging or other means, a continuous flow can be initiated. It is submitted with respect that no size of tubing or casing can be calculated to deal with the fluctuating conditions of an oil well.

Thanks are due to Mr. Chapman for calling attention to the influx of sulphur on circulating steam in a Mexican well. This is certainly an unusual occurrence, and there are few oilfield conditions where this could be repeated; nevertheless, the record of such a circumstance is a valuable warning.

Mr. A. J. Goodman calls attention to an article which had not been brought to the notice of the author, but it is satisfactory to notice that Mr. Campbell's studies had led him to account for the freezing of Turner Valley wells by expansion of gas escaping from limestone debris which imposed sufficient resistance to flow to cause a considerable differential pressure at the base of the well. This explanation does not differ greatly from the one submitted in the paper.

In reply to Mr. Capito's contributed remarks, the author replies that he had in view a smaller finishing diameter than those mentioned, even to 4½ or 3 in. for deep, high-pressure wells. This course is suggested partly to reduce the cost of drilling and lining holes, and partly to restrict flow without the necessity of introducing flow tubing. As the main object of modern production methods is to curtail the rate of flow of wells in new fields developed on a unit plan, so that the reservoir rock is not disintegrated and the gas-oil ratio is kept within limits which ensure the maximum benefits of dissolved gas, it would appear unnecessary to finish holes with a diameter far larger than that needed to satisfy demands, provided there are no mechanical difficulties in drilling. Complete agreement is felt with Mr. Capito's view that no larger ultimate production would result from a small-diameter well than from a larger one furnished with flow tubing, provided that the same measure of restriction was imposed to ensure efficient discharge. Unfortunately the use of larger casing gives a wider latitude for inefficient operations and also constitutes a menace when high back pressures are held, for in the event of a blow-out far more serious consequences may result than from a small-diameter well.

As regards the eventual employment of artificial methods of extraction, it is submitted that the effective control of production from pools under unit operation would result in the economic exhaustion of the oil-bearing rocks by natural flow. This ideal should be approached, and appears likely to be approximated in some of the modern-developed fields. Roof falls or caving would certainly not account for the Rumanian wells turning to gas, for in two cases water at a later period was forced against high pressure into wells which had gone to gas after big oil productions, in order to suppress nearby blow-outs which had resulted from failure to control high pressures. The change to gas was a gradual

process and not sudden, and no important quantities of sand were expelled.

It is feared that no useful figures can be submitted to show whether better results can be secured by drawing from a succession of sands simultaneously than by developing each sand or sandy group separately; nor is it possible to make trustworthy comparisons of the ultimate yield of wells resulting from controlled and open flow. The main point is that open-flow methods could be fairly safely practised in low-pressure shallow fields, whereas they are impracticable in high-pressure deep fields. An uninterrupted flow of 3,750,000 barrels of oil in 30 days, accompanied by about 300,000 tons of sand, from a well about 1500 ft. deep has been recorded in the Baku oilfields, and this would be difficult to excel by any methods, old or new. Where oil sands are highly lenticular in character, it is very difficult to say how best to secure the greatest ultimate yield. In 1892 the average ultimate yield of 448 wells in the Baku oilfields was 650,000 barrels by open-flow methods and bailing, but the sands were unusually thick and prolific, and as no oilfields in the world have proved so rich it would be unfair to use these figures as a basis for comparisons. Most practical oilfield operators agree that unrestricted flow for brief periods is beneficial, but it can rarely be practised with safety under very high-pressure conditions.

A Study of Energy in Relation to Production of Oil.*

By S. F. Shaw, M.Am.Inst.M. & M.E., Assoc.M.A.A.P.G. (Member).

The study of energy in connection with production of oil is receiving increasing attention. A discussion of the energy required to move the oil through the sand and to lift to the surface may, therefore, be of interest.

It is obvious that the lifting of oil from an oil sand requires that work may be done in the operation. If there be sufficient pressure in the reservoir, the oil may be lifted through the bore hole merely by being pushed or squeezed out of the sand. This is the condition found in artesian water wells. Such a condition would require a pressure at the bottom of the well equal to :—

Depth in feet $\times$ 0·434 $\times$ specific gravity of the oil.

Ordinarily the pressure in the oil sand is not sufficient to perform the lifting of the oil in this manner, and even in the cases where the pressure is sufficient the effect lasts only for a short time. The gas associated with the oil and under the same pressure as the oil, usually furnishes the energy necessary to lift the oil where flowing wells are encountered.

In lifting oil, the work in footpounds performed is equal to the weight of a barrel of oil multiplied by the number of feet that the oil is lifted. Thus, if the distance that the oil is lifted be 2000 ft., and the oil has a specific gravity of 1, the work performed in lifting one barrel would be :—

2000 $\times$ 350 or 700,000 footpounds.

In expanding isothermally from a given gauge pressure to atmospheric pressure at sea level 1 cu. ft. of a perfect gas can perform work as noted in Table No. I. :—

Table I.

Footpounds of Work Performed in Expanding from a given Pressure to Atmospheric Pressure.

Pressure.	Footpounds.
100	4329
200	5676
300	6486
400	7069
500	7527
600	7902
700	8222
800	8499
900	8744
1000	8964
2000	10,414
3000	11,294

* Paper received September 29, 1931.

If no losses occurred in expanding from 500 lb. per sq. in. to atmospheric pressure, the number of cubic feet of gas that would be required to lift one barrel of oil of a specific gravity of 1 to a height of 2000 ft. would be as follows:—

$$\frac{2000 \times 350}{7527} \text{ or } 93 \text{ cu. ft.}$$

Losses occur in various forms, and a factor for the efficiency obtained under the various conditions must be applied to this result of 93 cu. ft. in order to obtain the actual number of cubic feet of gas consumed during the operation. If the conditions were such that a lifting efficiency of 25 per cent. were obtained, the required amount of gas would be:—

$$\frac{93}{0{\cdot}25} \text{ or } 372 \text{ cu. ft.}$$

In air-lift practice we are accustomed to the term "submergence," which ordinarily refers to the number of feet that the flow pipe is submerged in the liquid. The percentage of submergence is the figure obtained by dividing the feet of submergence by the total length of the flow pipe. Thus, if the total length of pipe is 4000 ft., and the submergence is 1000 ft., the percentage of submergence is 25 per cent. Usually we cannot actually measure the submergence when lifting oil from a well, but we have a pressure condition equivalent to submergence which can be measured or observed.

The conditions under which an air lift is operating has an important bearing on the efficiency that will be obtained. A rule-of-thumb figure for the efficiency that can be expected for an air lift operating at maximum capacity under fairly favourable conditions would be equal to the figure for percentage of submergence. Thus, if the submergence is 25 per cent., we might expect to be able to obtain an efficiency of about 25 per cent. This relation between efficiency and submergence is not a straight line relationship. It varies with changes in conditions, and these conditions vary between wide limits, but for the purpose of discussing lifting operations this rule-of-thumb relation will serve fairly well. If operations be conducted at maximum lifting efficiency instead of maximum capacity, the percentage of efficiency obtainable will be somewhat greater than the percentage of submergence.

If we assume conditions as follows:—

Depth, 4000 ft.
Pressure at the bottom, 500 lb. per sq. in.
Specific gravity, 1,

we would have a submergence of 1152 ft. and percentage of submergence of 28·8. For this condition, a lifting efficiency of 28·8 per

cent. could be expected, when lifting at maximum capacity of the pipe. The lift would then be 4000 ft. less 1152 ft., or 2848 ft. The quantity of gas under pressure of 500 lb. per sq. in. required to lift one barrel of oil would then be :—

$$\frac{2848 \times 350}{7527 \times 0{\cdot}288} \text{ or } 460 \text{ cu. ft.}$$

Let us apply this method of calculation to flowing wells having depths of 4000 and 3000 ft.; oil having a specific gravity of 0·91 (24° A.P.I.) and having bottom hole pressures and back pressures as given in Table No. II. Results would be as follows :—

TABLE II.

Data applying to Wells having depths of 4000 ft. and 3000 ft. and Flowing under assumed Conditions of Pressure.

Example.	Bottom-hole pressure.	Ft. lbs. in 1 cu. ft. of the gas.	Back pressure.	Ft. lbs. in 1 cu. ft.	Net available ft. lbs.	Feet sub-mergence.	Feet lift. 4000′	Feet lift. 3000′
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	1000	8964	700	8222	742	2532	1468	468
2	800	8499	500	7527	972	2025	1975	975
3	600	7903	300	6486	1416	1519	2481	1481
4	400	7069	150	5115	1954	1013	2987	1987
5	200	5676	50	3137	2537	507	3493	2493
6	100	4349	0	0	4349	253	3747	2747
7	1000	8964	150	5115	3849	2532	1468	468

Example.	Per cent. sub-mergence.		Per cent. efficiency.		Ft. lbs. required to lift 1 brl. oil (0·91) the necessary distance.		Cu. ft. gas at given bottom-hole and back pressure required to lift 1 brl. oil at 100% efficiency.		Cu. ft. gas required to lift 1 brl. oil at obtainable efficiency.	
	4000′	3000′	4000′	3000′	4000′	3000′	4000′	3000′	4000′	3000′
	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
1	63·3	84·4	63·3	84·4	467,558	149,058	630	201	995	238
2	50·6	67·5	50·6	67·5	629,037	310,537	647	319	1279	473
3	38·0	50·6	38·0	50·6	790,198	471,698	558	333	1470	658
4	25·3	33·8	25·3	33·8	951,359	632,859	487	324	1925	959
5	12·7	16·9	12·7	16·9	1,112,520	794,020	438	313	3450	1852
6	6·3	8·4	6·3	8·4	1,193,419	874,919	274	201	4350	2431
7	63·3	84·4	63·3	84·4	467,558	149,058	121	39	191	46

In studying the figures in Table No. II., it will be seen that the figures for available footpounds of work in column 6 are obtained by deducting the figures for footpounds in column 5 from those in column 3. It is obvious that the energy left in the gas at the back pressures assumed is not available for lifting oil. In calculating the figures for column 14, it is necessary to multiply the footpounds of work required to lift one barrel of oil at 1 specific gravity by 0·91, since the specific gravity of the oil is assumed

to be 24° A.P.I. or 0·91 specific gravity. The figures in column 14, divided by the figures in column 6 will give the quantity of gas under the given back pressure required to lift one barrel of oil to the height noted in column 8.

The difference between the quantity of gas at pressure of 1000 lb. required to lift one barrel of oil with back pressure of 700 lb., and that under pressure of 1000 lb. but with back pressure of 150 lb. is very marked, as noted in examples 1 and 7.

The figures in Table II. give the approximate quantity of gas required to lift one barrel of oil under the assumed conditions, whether the gas be found in the reservoir, or whether it be supplied by compressors, provided those gases be made up of the same physical constituents. In actual practice, however, gas accompanying oil of high gravity may be made up of important percentages of propane, butane and heavier gases, which do not follow Boyle's law as closely as does air, methane or ethane; consequently in gases containing considerable quantities of these heavier constituents certain allowances would have to be made when calculating lifting performances.

The quantity of gas that can be dissolved in California crude of 25° at the various pressures assumed in Table II. is given in Table III.[1]:—

TABLE III.

Quantity of Gas that can be Dissolved in one Barrel of Californian Crude.

Example.	Bottom-hole Pressure.	Cu. ft. Gas. Dissolved in 1 Brl.	Back Pressure.	Cu. ft. Dissolved in 1 Brl. Oil.	Difference in Quantity of Gas Dissolved in 1 Brl. Oil.
1	1000	194	700	133	61
2	800	153	500	94	59
3	600	113	300	54	59
4	400	72	150	21	51
5	200	26	50	5	21
6	100	13	0	0	13
7	1000	194	150	21	173

The graphs given in the charts by Dow and Calkins are extrapolated to give the quantity of gas dissolved in oil under pressures that are higher than those found in the Dow and Calkins charts.

In example 1 of Table II., column 19, for pressure of 3000 ft., it will be noted that with the bottom-hole pressure of 1000 lb. and back pressure of 700 lb. there will be required approximately

[1] Dow and Calkin, U.S. Bur. of Mines Reports Invest., 2732, 1926.

244 cu. ft. of gas to lift one barrel of oil. Under these assumed conditions it will be observed from Table III. that 61 cu. ft. is available from one barrel of oil, consequently 183 cu. ft. of gas must be removed from the oil reservoir to lift this barrel. In example 7, where the bottom-hole pressure is 1000 lb. and the back pressure is 150 lb. there will be required 46 cu. ft. of gas to lift a barrel of oil, and since 173 cu. ft. of gas is available for lifting purposes in each barrel of oil, it will not be necessary to remove additional gas from the sand. It is not possible, of course, to produce this barrel of oil with less than 194 cu. ft. of gas since this quantity is dissolved in the oil and cannot be squeezed out and left in the sand.

Back pressures may be held at the surface by flow nipples at the well head, and tests can be made from time to time to determine the quantity of gas that flows with the oil under different conditions of bottom-hole pressure and of back pressure. If the flow nipple at the well is enlarged where a high casing-head pressure exists, the production of oil is usually increased, and the back pressure is usually reduced, as is also the bottom-hole pressure. It will be observed in Table II. that a reduction in bottom-hole pressure nearly always requires the expenditure of a greater quantity of gas to lift a barrel of oil, since this reduction in pressure means that the gas contains a smaller amount of energy per cu. ft.; also, because the height to which the oil must be lifted is greater. If the quantity of gas per barrel in a well flowing naturally is increased, it means that the gas-oil ratio has been increased, since there is no place from which the energy may be obtained for lifting purposes other than from the oil reservoir. In a well produced by gas-lift, however, conditions may be such that part of the gas required for lifting is supplied by compressors, making it unnecessary to rob oil not lifted of part of its gas to make up the deficiency of gas in the barrel of oil lifted.

Every barrel of oil, and every cubic foot of gas extracted from the sand, is accompanied by a reduction in pressure in the oil reservoir. This decrease in pressure is not noticeable for small quantities removed; nevertheless, there is a definite decrease of pressure, even though it be too small to be measured. This means that every cubic foot of gas remaining in the sand is gradually becoming reduced in its potential energy. It also means that the distance through which the oil must be lifted is gradually increasing. The inevitable result is that the quantity of gas required to lift a barrel of oil gradually increases as oil and gas continue to be produced from the reservoir.

As the well becomes older, particularly if the well be one that is flowing naturally, it is usual to observe an increase in the gas-oil

ratio. The additional energy required for lifting the oil furnishes one reason for an increase in the gas-oil ratio, as has previously been noted. Also, the oil is being derived from a distance from the well that is continually increasing; consequently additional energy must be provided for this purpose, whether the oil be produced by natural flow, by artificial gas-lift or by the pump. But this increase in the gas-oil ratio, when there be such required to move the oil to the well should be carefully distinguished from the increase in gas required for the mechanical operation of lifting the oil from the reservoir to the surface.

In the examples given in Table No. II. we can readily see why there is an increase in gas-oil ratio in a well flowing naturally. In example 1, the amount of gas in a 3000 ft. well required to lift a barrel of oil is about 244 cu. ft., whereas in example 6 the quantity of gas required per barrel of oil is 2431 cu. ft., after the flowing pressure had declined to 100 lb. If the well continues to flow naturally, and if the bottom-hole pressure remains at 100 lb., there is no way by which to reduce the gas-oil ratio below 2431 cu. ft. per bbl. Conditions might be such, however, that the gas-oil ration might be reduced by employing the gas-lift.

We have been accustomed to accept this increase in the gas-oil ratio as unavoidable, but experience in gas-lift wells covering the productive life of many wells has indicated that there was little need for an increase in the fixed gas-oil ratio. In wells producing oil of low gravity, where the gasoline vapours are negligible in quantity, the gas-lift has produced in many instances with no increase in the gas-oil ratio. On the other hand, wells on gas-lift, where the oil was of high gravity and contained considerable gasoline vapours, the gas-oil ratio has seemed to increase, but tests made from time to time are leading to the conclusion that the actual fixed gas-oil ratio, composed of methane and ethane, has not shown any appreciable increase.

Several attempts are being made at this time in new fields to maintain the pressure in the reservoir by returning the gas to the sand, and the outcome of these experiments will be awaited with much interest. Whether channelling will take place remains to be seen. It must be understood that maintenance of pressure is only a relative term, since there is no way to actually maintain the pressure without returning more gas to the sand than that actually removed, because of the removal of oil. For instance, if the original pressure in the reservoir be 2000 lb., and the oil has a dissolved content of 350 cu. ft. of gas per barrel, the return of 100 per cent. of the gas would serve to maintain the pressure by only one-third greater amount than if no gas at all were returned.

This is due to the fact that the additional quantity of gas at 2000 lb. per sq. in. required to fill the space denuded of the oil itself would amount to about 770 cu. ft. for each barrel of oil removed.

In Table IV. there is given the footpounds of work given out by a perfect gas when expanding isothermally from a given pressure to a given lower pressure :—

TABLE IV.

Foot pounds of Work given out by one cu. ft. of a Perfect Gas when expanding isothermally from a given Gauge Pressure to a Lower Pressure (Sea level basis).

Lower pressure.	1200	1100	1000	900	800	700	600	500	400	300	200	100	50
900	—	—	220	—	—	—	—	—	—	—	—	—	—
850	—	—	339	119	—	—	—	—	—	—	—	—	—
800	—	—	465	245	—	—	—	—	—	—	—	—	—
750	—	—	599	379	134	—	—	—	—	—	—	—	—
700	—	—	742	522	277	—	—	—	—	—	—	—	—
650	—	—	900	676	431	154	—	—	—	—	—	—	—
600	—	—	1062	842	597	320	—	—	—	—	—	—	—
550	—	—	1241	1021	776	499	179	—	—	—	—	—	—
500	—	—	1437	1217	972	795	375	—	—	—	—	—	—
450	—	—	1653	1433	1188	911	591	216	—	—	—	—	—
400	—	—	1895	1675	1430	1153	833	458	—	—	—	—	—
350	—	—	2166	1946	1701	1425	1104	729	261	—	—	—	—
300	—	—	2478	2258	2013	1734	1416	1041	583	—	—	—	—
250	—	—	2845	2625	2380	2103	1783	1408	950	367	—	—	—
200	—	—	3288	3068	2823	2546	2226	2050	1393	810	—	—	—
150	—	—	3849	3629	3384	3107	2787	2412	1954	1371	561	—	—
100	—	—	4615	4395	4150	3873	3553	3178	2720	2137	1327	—	—
50	—	—	5827	5607	5362	5085	5827	4390	4932	3349	4539	1212	—
0	—	—	8964	8744	8499	8222	7902	7527	7069	6486	5676	4349	3177

For instance, if a gas expands from rock pressure of 1000 lb. per sq. in. to a pressure of 600 lb. by the time the gas has reached the well, there has been performed 1062 footpounds of work, which is available for moving oil through the sand. If the rock pressure has become reduced to 200 lb. and the gas expands to a pressure of 50 lb. by the time it has reached the well, it has performed 4539 footpounds of work, or more than four times as much work as when expanding from 1000 lb. to 600 lb.

From this study it may be seen that it may be possible to move oil through the sand with no increase in the gas-oil ratio as the well becomes older, even though the oil must be moved through a greater distance in reaching the well, because of the greater available energy in a cubic foot of gas under these conditions of reduced pressure. If, however, the oil were to be lifted to the surface by natural flow, we find by examination of the performance of gas in lifting oil that it would require many times the quantity of gas per barrel of oil to lift it to the surface when the gas is under a

bottom-hole pressure of 50 lb. than when under a bottom-hole pressure of 600 lb., and if the well were being flowed, naturally we would call it the gas-oil ratio, even though it might be several times greater than the quantity of gas necessary to move the oil through the sand to the well.

In connection with the above, **Mr. J. T. Hayward** writes:—

Mr. Shaw states in the paper that a rule-of-thumb figure for the efficiency that can be expected with proper design and operation is equal to the percentage of submergence. This should prove a valuable guide and be of great assistance in the field.

The basis used in the paper for calculating the efficiency is the work theoretically obtainable from a perfect gas expanding from the bottom-hole pressure to the surface back pressure. As used by Mr. Shaw, namely, as a basis for comparison, isothermal expansion is a useful standard—perhaps the best and simplest available. Unfortunately, judging from other published work, its use has led to serious misunderstanding and isothermal expansion has been used not as a standard for comparison, but as a guide to the ideal conditions to be arrived at in a flowing well.

It has to be remembered that the area of the P.V. diagram represents the net work available only when the expansion takes place under a frictionless piston *and without eddying*. Isothermal expansion in a turbine or a flow column represents no work done and zero efficiency. Actually the *smaller* the P.V. diagram the *higher* the efficiency.

Suppose two vessels connected by a pipe and gas flowing under a differential pressure from one to the other. Work done against friction in the pipe and eddy losses is returned as heat to the gas, so that the initial and final temperatures are the same with a perfect gas. If now a small turbine is intercalated in the connecting pipe between the vessels and the gas in passing from one to the other does useful work, the final temperature will be lowered in proportion to the net useful work done and the area of the P.V. diagram correspondingly reduced below that of the constant temperature diagram.

Similar reasoning applies to the flow column of a producing well. Neglecting for the moment the work done by the gas in raising itself, and assuming a gas-oil slip of 100 per cent., there would be no external work done and, therefore, no temperature drop and a P.V. diagram of the constant temperature and maximum area type. If the velocity is increased and oil lifted to the surface there will be a temperature drop the thermal equivalent of the useful net work done, a smaller terminal volume per pound of gas due to the lower temperature and consequently a reduction in the area of the P.V. diagram.

In other words, the oil and gas mixture starts at the bottom of the column with a definite available energy content equal to the mechanical equivalent of the internal energy of the gas and of the sensible heat in the fluid, both of which are proportional to the temperature. Friction and eddy losses do not reduce the temperature, but the *greater* the proportion of useful net work done, the *larger* the temperature drop, the *smaller* the P.V. diagram and the *higher* the efficiency.

The temperature drops considered above are, of course, superimposed upon the Joule-Thompson effect due to the imperfection of the gas in an actual well and upon the cooling due to the latent heat of evaporation of the fractions vaporising in the column.

Progress in Rectification of the Light Petroleum Hydrocarbons.*

By S. C. Carney.

A most fruitful and very interesting period in the development of rectification began with the address of J. A. Rafferty, before the Annual Convention of the Natural Gasoline Association of America, at Tulsa, in 1923. Beginning a period at this point is of course for the purpose of the present discussion, and is in accordance with the licence which custom grants the historian.

Mr. Rafferty, at this time, followed previous informal statements by announcing the practical commercial separation of propane and butane from materials of petroleum origin. The author, who usually engaged in the discussion at these annual meetings, was not present at this one, and so is happily spared the memory of having publicly announced the scepticism which has been bred in him by too close reliance on the statements of the technical and scientific literature of that date. For this reason he is disposed to pass on without quotation from the minutes of that meeting, though his scepticism was shared by numerous others.

This announcement was made to a group of men whose environment had taught them several simple things, some of which had been largely lacking in the environment of rectification before that time. They were accustomed to operating with pressures up to 300 lb., had seen and handled large quantities of highly volatile liquids, were not much concerned with fuel economy, and were accustomed to regard a liquid which flowed downward against a rising column of vapour as a solvent. They also had placed their operations almost entirely under automatic control. On the other hand they had an aversion to high temperatures, even of the atmospheric order, and had been unfortunate in experiments with refrigeration. They thought of temperature rather than of heat, and, in the new process being discussed, were interested in the residue rather than in the top product of rectification. It will be seen that in many respects these mental attitudes were in direct antithesis to those under which rectification had previously been studied. Chemists had worked at low pressures, had thought of butane as a gas, had seen but minor amounts of liquids of low boiling point, and had to pay for the fuel they used. Oil refiners had a similar chemical background; considered reflux as a cooling medium, nearly always fed their columns with vapour, but were chiefly interested in the overhead products.

A much more universal feature of environment is the atmospheric pressure, nominally 760 mm. In consideration of this, which affects

* Paper received September 24, 1931.

both people and butane, it will be seen that it was the work in which the various persons had been engaged that affected their mental attitudes. All of them were right in their own environments, but too narrow in their attitudes.

The older chemists had established boiling points as useful in the profession and the younger ones had sometimes failed to remember their connection with pressure, so they considered butane usually as a gas; and the fact is, it is to-day being sold and utilised as a gas. The refiners had as one of their chief distilling problems the complete stripping of gasoline from fuel oil, and had correctly learned that high pressure is not useful for that. The natural gasoline operator had as his chief problem the partial condensation of a mixed vapour and had learned that high pressure, either high total or high partial pressure, was useful for that, but he also realised that he could not afford to buy pressure storage for all the liquids he could condense, and so watched with a jealous eye the rise of temperature in his storage tanks. Progress in rectification has been in direct ratio with the rate at which more people have utilised sound knowledge of these very simple physical laws. Hausbrand wrote, in 1915, that the facts governing rectification were more simple than generally supposed. There still remains a rather general failure to consider all the simple physical laws at the same time, but with the use, for example, of mathematical methods such as the Murray formula[1, 2] this is rapidly being corrected.

Mr. Rafferty, in 1923, proposed the stabiliser. His underlying purpose was to secure a supply of chemical raw material for some of the operations since so successfully carried out. His audience needed and very rapidly accepted it for solving their physical problems. The first units were designed by persons who considered propane as a liquid boiling at —45° F. They followed refinery practice in including a large boiling vessel. They used a column soundly designed as to size and number of plates, recognised the point of introduction of feed with respect to its composition, and operated the column at substantially atmospheric pressure. The reflux, however, was condensed at much higher pressure at the temperature attainable by cooling water.

Next followed installations of units operated at higher pressures. This type was described by Mr. J. H. C. De Brey, in 1918, and a U.S. patent was granted him in 1923. These units also had columns soundly designed (following Hausbrand); their reflux condensers were at the top of the column and at the same pressure, and also included

[1] W. J. Murray. "The Compression of Refinery and Casinghead Gases." *Ind. Eng. Chem.*, 1929, **21**, 917–919.

[2] W. F. Cerini. "Gasoline Plant Design." *Petr. Eng.*, Feb., 1931, **1** (5), 84.

boiling vessels of substantial size. The words "soundly designed" should be qualified by saying that the effect of operating pressure on the number of plates was not so well understood as it is now and that sound design for a feed containing four or five components is by no means yet understood.

Patents on both types for the purpose of removing propane from natural gasoline came under one ownership but, after the licensing of a few of the low-pressure type, some members of the industry built and operated the high-pressure type unlicensed. Litigation followed which resulted finally in the courts holding both patents invalid. This litigation, so casually mentioned, was however, carried with much skill and determination by both sides. It has had a very important effect on the progress of the art. The entire history of the art was brought out and studied, not only by the litigants but by many others in the industry affected.

Since the plaintiff made good use of an analytic method, at first undisclosed, the defence also developed a method which with numerous modifications is now in general use. There is some difference of opinion as to just how this method was developed, and the preceding sentence is only the author's opinion. A detailed description of its history and present form with bibliography has recently been written by Walter J. Podbielniak,[3] to whose capable and persistent effort its present general use is undoubtedly due.

The use of boiling vessels of substantial size on continuous units was an early subject of discussion. One opinion was that they served to prevent rapid changes in temperature and by furnishing disengaging area at the liquid surface to avoid entrainment of liquid in the vapour entering the column. The other view was that the large body of liquid there present served as a reservoir of sensible heat which, on a decline in operating pressure, caused a flashing of vapour leading to flooding the column, and that, if vapour velocity were not too high in the column section, it would not be sensibly greater below the lower plate if vapour came from a compact heating surface. Since heating surface in compact tube bundles of much greater efficiency than the old coils in a tank was being manufactured and boiling vessels of large size for pressure operations were expensive, and some of the second opinion had demonstrated that a column so built would operate, the large boiling vessels were largely abandoned and are rarely seen to-day. Experience also rapidly settled the predominant opinion in favour of the water-cooled pressure type as against the low-pressure refrigerated type. Probably economics here too prevailed because the low-pressure type

[3] "Apparatus and Methods for Precise Fractional-Distillation Apparatus." *Ind. Eng. Chem.*, Anal., 1931, **3**, 177-188.

required a very substantial investment in compressors to produce the necessary refrigeration.

In June, 1925, was published a paper by McCabe and Thiele[4, 5, 6] which, so far as technique is concerned, and aside from the historical situation that gave it a wider audience than it would otherwise have had, might be thought a more logical point to begin a period than the one that has been selected. This graphical method of design of the rectifying column has won general acceptance, and has largely superseded earlier methods. It is generally agreed that this static method soundly considers the principles underlying the separation of two component mixtures by means of ideal plates on which equilibrium is attained. Although distillation is an ancient art, what is here called rectification is not, and it is of interest to note that still, in 1915, accepted authorities were reporting experiments to determine the fractionating efficiency of the constant temperature condenser, though at that same time a relatively few mathematicians understood the principles and had by material balances arrived at substantially the results which McCabe and Thiele were able to present in such simplified form. And it is the author's opinion that the engineering science of the subject which will consider the column as a working machine of which one should use for a given problem a number soundly to be determined, each having a suitable design, and operated in proper cycle is yet largely to be developed.

At this time, 1925, rectification as a means of producing commercial natural gasoline of high distillation recovery, which was the commercial standard established by the Association of Natural Gasoline Manufacturers, was being adopted. The word propane was in colloquial use and the industry began to hear vapour pressure mentioned in referring to the property of a liquid rather than to a rule of the Interstate Commerce Commission. The industry was growing and prices were such that it was obviously profitable to export natural gasoline to Europe. Such export had been moving as blends, but now a unit was built at a Gulf port for handling 6500 barrels per day, removing entirely the approximately 3 per cent. propane currently left in commercial material and manipulating the butane content as required by physical laws when shipping unblended in tank steamers and by commercial requirements when shipping blended with heavier material. This installation demonstrated that the then current operating practice of attempting to hold constant temperature together with constant pressure at both top

[4] W. L. McCabe and E. W. Thiele, "Graphical Design of Fractionating Columns." *Ind. Eng. Chem.*, 1925, **17**, 605-611.

[5] L. H. Shirk and R. E. Montanna. "A Critical Analysis of Equations for the Design of Fractionating Columns." *Ind. Eng. Chem.*, 1927, **19**, 907-911.

[6] T. Baker and J. S. Stockhardt. "Graphical Rectifying-Column Calculations." *Ind. Eng. Chem.*, 1930, **22**, 376-377.

and bottom of a column was unsound. For the composition of the feed which came by railway tank car from a number of sources was more obviously and suddenly variable than the feed to the former smaller installations whose feed was produced by the same plant. The word " butane " now began to be heard in trade circles because some plant products by reason of better rectification at the plants began to contain entirely too much of it for this export purpose. One soon saw 10,000 barrels of that butane which was so sceptically discussed in 1923 stored in one pressure tank. But the project was successful and it was soon proposed to enlarge the capacity to 10,000 barrels per day. It had become apparent why butane was easy instead of impossible to produce by rectification and, more important still, why propane did not come out here so easily as at the installation in the producing plants. There was less of it and practically no methane and ethane to furnish the accustomed freedom of composition in the condensers.

Now is stated probably the most elementary point in rectification. It was known to the ancients, and it is implicit in all the calculations; no one will deny it, yet overlooking it is far too prevalent still to-day. " It is easier to recover a component in purity when there is plenty of it in the feed." Earlier workers had not learned how to separate propane and butane because their attention was directed to the " efficiency of the still head," the accuracy of temperature control and other mechanics of the process, while working with a material which contained them in but very low concentration.

In the extension of the export plant two columns were used in a manner unorthodox in petroleum rectification. For producing propane and butane the orthodox procedure had been to take propane from the top of the first column, operating at 150–200 lb. gauge, then feed the bottoms of the first column to a second at a lower pressure, *e.g.*, 80 lb., and take butane from the top of it. This was reversed; from the top of the first column at 80 lb. was taken as a liquid the propane *plus* the desired amount of butane. This top product was pumped as a liquid into the feed of the second column operating at 150–200 lb., it producing propane as top product and butane as bottom product. The advantage in this simple case is fairly obvious. Looking at concentrations first, if there be 3 per cent. propane and 30 per cent. butane in the original feed, there may be 15 per cent. propane and 85 per cent. butane in the feed to the second column, with far less gross amount. The heavier fractions of the original feed are heated to a much lower temperature, and the lighter material in the kettle of the second and smaller diameter column requires a much lower temperature there to produce the pressure requisite to condensing a

propane reflux with cooling water. The low vapour pressure material from this installation, such as was shipped unblended in unaltered tank steamers, demonstrated that natural gasoline was more susceptible of storage and transport than had previously been thought. It was soon produced in other installations under somewhat closer specifications and substantial amounts sold as aviation fuel.

Successful operation of large scale units attracted the attention of refiners and, following the court decisions invalidating the patents, development in many directions was so rapid that chronological order is not attempted. Any way, there is a difference of opinion as to which refiner first used rectification on cracked distillates. This development, which is to-day vigorously growing, is for a combination of chemical and physical purposes. It was first called in the trade "stabilisation," then "desulphurisation," then "debutanisation." The technique, though not different in principle, is much more complicated in practice than the rectification of natural gasoline. A recent paper by A. W. Burket[7] discusses the very numerous factors pertinent, and an article by Wilde, Mead and Coleman[8] describes a more specific case, having in mind the avoidance of, rather than providing remedy for, storage and handling losses.

With natural gasoline, acceptance of rectification is complete, all plants rectify the product as local conditions indicate. Parallel with this development has grown the practice of marketing propane and butane as such. This general subject is described by L. H. Wright,[9] who analyses the report of U.S. Bureau of Mines showing the sale of 18 million gallons of liquefied petroleum gases in 1930. Emby Kaye[10] has described in more detail the evolution through which the supplying, as town gas, of butane vapour diluted with air, has already gone. Pentanes are included in this total figure, the major part still being propane, 11,500,000 gallons. Sales for 1930 increased 80 per cent. over 1929 and construction in progress indicates that consumption of butane for fuel purposes will soon pass propane.

Pentane has for several years been produced as a chemical raw material, being chlorinated as the first step. There are little signs of growth in this, but the rectification of pentane has, generally speaking, been done by natural gasoline producers also, and its use in competition with propane as domestic fuel for isolated

[7] "Vapour Recovery Plant Design based on Survey of Specific Conditions." *Nat. Petr. News*, 18.3.31, **23** (11), 61.
[8] "Methods Outlined to Decrease Losses," *Oil and Gas J.*, 3.10.29, **28** (20), 222.
[9] "Liquefied Petroleum Gases." *Petr. Eng.*, Apr., 1931, **2** (7), 110.
[10] "Butane-Air Gas Business." *Petr. Eng.*, Mar., 1931, **2** (6), 68.

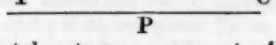
installations is having substantial growth. As compared with propane it obviously may be shipped in much cheaper containers.

As a parallel growth, the separation of olefines, mostly by the chemical industry, has proceeded with little publicity. Again the simple fact of concentration governs. Olefins are chiefly separated from specially cracked materials, the process being so conducted as to produce a material containing substantial amounts of the desired olefine. Ethylene was first, and is probably still, produced in largest quantity. More recently, propylene, butylene and amylene are being separated from commercially cracked gases and liquids in varying degrees of purity. As molecular weight increases such separations obviously increase in difficulty because of the rapidly increasing number of isomers. But, for example, it is quite possible with a commercially practical steam consumption, to produce 90 per cent. butylene (a mixture of normal and iso-butylene) by rectification from between the paraffins, iso and normal butane, or to vary the content of the highly reactive iso-butylene in a fraction containing only materials of four carbon atoms from 5 per cent. to more than 80 per cent.

The future of refinements of petroleum rectification lies in such work as this, and development will go as governed by the economics of the case. The growing use of rectification as an aid in refinery chemical treatment, principally by rectifying out most of the hydrogen sulphide, has its further possibilities suggested in the Bulletin No. 333 of the U.S. Bureau of Mines, much further work on this possibility being in progress. It is being realised that one can do a lot of rectification for the cost of a relatively small amount of chemicals. Furthermore, every fraction separated for one purpose affords a possibly advantageous material for another.

The foregoing has been historical or almost reminiscent. It has been the intent to show the rapid development of breadth in the subject while intentionally staying away from the technical details. Pressure has been mentioned frequently, the importance of composition has been suggested, but little has been said about temperature, for in the past too much attention has been given to temperature.

The relation of temperature, pressure and composition under the phase rule, as it affects the rectification of petroleum materials, may be simply given by a diagram :—



If composition be taken to mean per cent. of the light component that is, volatility or vapour pressure—and the line T. C., an inflexible lever, be fixed in turn at the points T. P. and C., it will be seen that pressure and composition rise and fall together, temperature

and composition move in opposite directions, and temperature and pressure rise and fall together.

This, of course, is nothing new, and amounts to saying that the system is bivariant, and that two of the variables must be arbitrarily chosen before it is defined, keeping in mind that composition is taken to mean vapour pressure even if five components are present.

In practically all rectifying operations, it has been the intent to fix temperature and pressure. Much of the time the pressure has been assumed to be atmospheric and constant, and it is in modern vacuum distillation practice that it becomes strikingly apparent how true the phase rule is, with reference to seemingly small pressure variations. Inaccuracies in the fixing of temperature and pressure are, of course, compensated by corresponding adjustments in composition which the materials in the column will make for themselves. In the usual commercial operations, including stabilisation, existing standards permit ample variation in composition to compensate for really large variations in temperature and pressure, and therefore permit serious errors in operation to pass unnoticed. The nominal propane from a stabilizer frequently contains methane, ethane and usually butane also. This sort of composition can and does adjust itself to the temperature and pressure at least as readily as would commercial gasoline, and the difference in composition between the liquid and vapour phase in the condenser is greater.

An explanation of fractional distillation is usually begun with the phase rule, and in all discussions much is said about equilibrium. In operation of columns, though, little is thought about either of them. One does not read many publications about the manufacture of substantially pure components from petroleum, even propane and butane, though these are being made in large quantities, but by relatively few people. The reason is that this requires a more skilled operation, not merely a column with more plates.

A mechanical analogy akin to the kinetic theory will tend to explain the finer points to which attention is being given in the recent rectification which approaches purity in its products. A column, from this point of view, is the frame and bed plate of a heat engine; the liquids and vapours therein, when it is in a given operating condition, are the moving parts. It converts heat into work, and the work it does is increasing the probability that molecules of a certain species, say propane, will occupy the top plate. It is a condition essential to its operation that both liquid and vapour phases exist at all times on each plate and in the kettle and condenser. Even more, for perfect operation, it is essential that the relative volumes occupied by each phase remain substantially constant. It is well enough understood what is meant by equilibrium on the ideal plate and the approach to it on the

actual plate. But this is a mechanical analogy. In mechanics a body which, when slightly displaced, tends to return to its original position, is said to be in stable equilibrium; if, when slightly displaced, the tendency is for the displacement to increase, it is said to be in unstable equilibrium.

The equilibria in an operating column are of the unstable variety.

If on any plate we have butane, boiling and in two phases, equilibrium will be maintained by the constant addition of more butane vapour. If, however, for any reason, a vapour containing also some pentane is added to that plate, there is a lowering of composition. This may be compensated, or rather will be compensated, by an increase of temperature, a decrease of pressure, or both. An increase in temperature can come only from the condensation of vapour from below to furnish the requisite heat. But the vapour from below already contains pentane. Without waiting for the heat to arrive to change the temperature of the substantial body of liquid in the plate, the pressure will tend to fall. But the pressure cannot fall, except enough to induce the flow of more vapour from below, vapour from above being sealed off (except in a packed column). Thus the entrance of a heavier component to a plate facilitates the entrance of still more of the heavier component, and the fact of its entrance does not of itself resist the entrance of more. This is what was described as the inherent instability of conventional columns. Furthermore, such a heavy component is only removed from the plate by dilution with reflux from above, and dilution is an asymptotic process.

True, from the point of view of static theory, the plate taken as an example may be equally in equilibrium after the addition to the pure butane which it originally contained of any amount of pentane. But, considering the plate of the example, as a part of a column whose purpose is the production of pure butane, the necessary equilibrium of butane existing in two phases, is on account of what is going on elsewhere in the column with pressure always in common, most unstable. The dimensions of the qualitative properties, pressure and temperature, and the quantitative property composition, the three being equally dependent variables will repay careful study.

This phenomenon is known to operators as "surging," and may be observed by accurate temperature observations over a period, in several contiguous plates, by which a higher temperature will occasionally be noted on a higher plate. The similar phenomenon, when occurring in the condenser, is known as "flooding," and is generally supposed to be due to excessive vapour velocity or too small down pipes, probably because reduction in the rate of application of heat or reduction in the cooling of the condenser or both,

will bring back the vapour phase which in extreme cases will have entirely disappeared in the upper part of the column and condenser, and thus permit the liquid reflux to flow down through the sealed down pipes. Water hammer in steam pipes is a similar phenomenon of liquid flow as affected by condensation of vapour of the same composition. It was also known in the older distillation at atmospheric pressure and cured by a vent to atmosphere on the condenser, through which enough air would enter to preserve two phases when the condenser temperature became too low to permit the material present to maintain its own vapour phase. The higher temperature of cooling water at the upper part of the condenser minimises but does not cure the tendency because the temperature of a pure vapour is unchanged by partial condensation.

The foregoing are the reasons why, it was stated earlier, that it is important that the relative volumes of liquid and vapour phases remain constant. While the phase rule itself is quite independent of these relative volume changes an operating column is not, because such a volume change can only occur at the expense of changes in rates of flow of vapour or reflux at some other point.

A principal item of progress recently is in a different conception of the function of temperature in rectification. Consideration shows that temperature is entirely different from the other measurable quantities of physics. It will be agreed that temperature of a boiling liquid, like the pressure of its vapour, is related to the kinetic energy of motion of the molecules. And, by the phase rule, at a fixed pressure, temperature of a liquid is dependent on its composition. For simplicity, in an earlier paragraph, composition was made synonymous with vapour pressure. For the present purpose its true meaning is taken, and thus where a large number of components are present in two phases the operating freedom is large and ample.

In the kettle of an operating column there are frequently many components, the number and relative amount of which fluctuate with variations in the composition of the feed and with variations in the column operation. At a fixed pressure temperature there can only be a very crude indicator of composition. The temperature there existing will infallibly be the one proper for the unknown material at the existing pressure, but the operator can never know what that should be except by empirical experience. But in the early days of stabiliser operation the attempt was made to fix not only the pressure but also the temperature at both the top and the bottom of the column. The top and bottom products were both sufficiently complex, and attempts to fix both these temperatures were sufficiently unsuccessful, so that the columns did operate on the reasonably constant feed after a fashion. Success

in fixing bottom temperature was so much greater, on the average, than success in fixing the top temperature that gradually the top temperature which had been variable any way was consciously permitted to vary within reasonable limits.

Meanwhile better pumps had been developed and experience had also taught that such light liquids could easily be pumped if the pump were cooler than the liquid to be pumped. (This has really meant, if the liquid were warmer than the pump) and condensers therefore are now generally located not at the top of the column as formerly but at a suitable location near the ground level and reflux pumped back to the column. The recent development has, in general, accepted the methods of design which have been mentioned, and recent progress has been chiefly in refinements of operation.

Operating practice is still almost universally based on a fixed pressure. For this control the pilot-operated instruments of several manufacturers have been developed to a high degree of precision. In most cases these are applied to the removal of top product as a vapour at such rate as will maintain the desired pressure. They are also used for the removal of top product as a liquid, although it is not yet generally understood that the effect in either case is really one of control of composition which results in an effect upon pressure, to say nothing of its effect also on temperature, which, with the present accurate regulators, is not so noticeable as formerly.

Thermostatic control of temperature in the kettle is still practised in many cases. An alternative which is largely used is that of maintaining on the heating surface of the kettle a constant steam pressure, which, of course, is the equivalent of a constant steam temperature there. A reducing steam pressure regulator is thus substituted for the thermostat. The result is that the temperature of the boiling hydrocarbon which receives the heat is free to vary at the constant pressure in accordance with its variations in composition. Meanwhile, the amount of steam used is thus proportioned to the throughput if its composition be constant. But with this and other types of operation the rates of flow, both of feed and of reflux, are to an increasing extent maintained constant by automatic flow controllers. If rate of feed be constant, the rate of application of heat by the constant pressure steam method will, of course, increase as volatility of the material in the kettle increases. This may or may not be theoretically sound. If the increase in volatility at the kettle be due to the increased presence of material which should go into top product, an increase in the heat used is correct, provided too much cooling at reflux condenser is not being done. If, however, an increase in volatility at the

kettle is the result of a decrease in the amount of some heavier component normally there, an increase in heating is not indicated.

The control of top temperature has likewise become more flexible. It is a fairly general practice to supply a fixed amount of water, the temperature of the water and not of the hydrocarbon being in some cases thermostatically controlled, and this condition is varied as indicated by periodic analyses of top product. In those cases where top temperature is permitted a certain flexibility, control there is usually by reflux control. That is, an automatic flow controller, which is actuated by the pressure differential across an orifice, governs the amount of reflux which is pumped back to the columns from an accumulator tank after the reflux condenser. In some cases propane so condensed and not used as reflux is sent to storage as a liquid, while vapours uncondensed are at the same time currently vented off by the back pressure regulator which operates as the pressure control. If such uncondensed vapours are also largely propane, fairly pure propane as a liquid may thus be produced, and in most cases high yields of propane are not required.

Speaking broadly, these developments are due to recognition that an element of flexibility is necessary in the operating column. The phase rule will not permit the early ideal of constant conditions while running a feed variable in both amount and composition. But examination will disclose that this flexibility is at the expense of composition, which in most cases may be permitted to vary sufficiently.

In those operations where the product is desired to have certain chemical properties, for example, sulphur content or olefine content, the much quicker chemical tests disclose variables not so apparent to the more elaborate and slower analysis of hydrocarbon mixtures by laboratory rectification. This has resulted in further broadening of the point of view. It may be correctly said that of any specific item under consideration there are three points of view; for example: (1) reflux is a liquid solvent which dissolves certain components of vapours; (2) reflux is a refrigerant, which by its evaporation removes heat from a zone to which it is introduced; (3) reflux is volatile material which raises the pressure if supplied, or lowers it if denied.

The type of control may always be classified as showing the point of view of its proponent. The truth of this has come to be generally recognised, and industry has reached the point where in some operations it is no longer permissible to utilise the flexibility afforded by variable composition as an element of operating practice. In finer work one approaches as a limit the condition where one component must exist in two phases if the column is to operate. Here is but one degree of freedom. If pressure be fixed

there is no freedom, and on a very minor operating change one phase must, and will, vanish.

The generally known types of operating control all require varying amounts of flexibility in composition. That is to say, for example, if propane is produced in reasonable purity, as it is, a substantial amount of propane, together with some ethane at least, is also taken as a vapour phase, and usually some propane, together with iso-butane and normal butane, occupy the kettle. Commercial butane contains both the iso and normal, and when produced as a top product the kettle generally contains also some butane and one or two pentanes, while if produced as a bottom product the top contains, generally, at least propane and some iso-butane.

If one examines, as they affect rectification, the factors of temperature, pressure and composition, some insight may be gained into the necessity of more careful analysis of the operating column as a mechanism, in addition to its static theoretical aspects.

First.—Composition is the chief fact about the feed and always defines the desired product. Static theory shows the influence of feed composition on products, necessary reflux and number of plates, but is too often considered as affecting only number of plates. In many cases one should not first begin to make the product, but should use perhaps two columns for the preparation of a feed from which the desired product may reasonably be made in a third. In many cases it will be practical to produce a pure product while taking but half of it from the feed, but not when taking it all. This need not reduce yield, for the remainder may in another column be reconcentrated to its original strength. A feed of seven components may, as an operating matter, be treated as one of two imaginary components, division being made at any point found strategically desirable. As operating strategy it is generally desirable to eliminate first the largest amount of material which is without interest for the purpose at hand, though in many cases it is desirable to eliminate first that material which offers greatest difficulty to the process. Methane or other material difficult to condense is an example of the last, and this strategy is sound with but little reference to whether they are high or low boiling. There are too many attempts to remove propane from pressure distillate before removing the gas oil and fuel oil. It is in matters such as these that rectification remains an art.

Second.—Pressure in an operating column can only differ between top and bottom by an amount equal to the resistance to flow, which is but small. Besides bounding a thermodynamic system, a column is a vessel in which fluids exist under pressure, and pressure is transmitted not only uniformly but very rapidly. When a pressure-actuated regulator vents material from the top, the

column responds first as a pressure vessel, and any change in pressure effects equally and at once all parts. If the top material be a pure substance and temperature remains the same, such a regulator will remove all material having that composition and regardless of the rate at which the column is able to produce it from the feed. New forms of control in which the rate of production of the top product, and not its vapour pressure, governs its removal are recently coming into use.

Third.—Temperature, which is the oldest guide in operation, and in many cases the only one, is now being assigned another rôle. From this point of view heat makes the system operate. Composition is what it is intended to produce; and the materials, if permitted to seek equilibrium, will correctly manifest their kinetic energy as temperature and pressure without assistance. This does not mean that the system is out of control, for the operator still decides within a reasonable range at what temperature he will remove heat at the top, and upon this decision and the composition rests the pressure.

To this end, it is found desirable that the liquid phase in process be reduced to the smallest practicable amount in order more nearly to equalise the time required for a change in temperature or in composition with that required for one in pressure. The advantage of this is illustrated in packed columns of small diameter which operate with throughputs, and degree of separation which in proportion to length and cross-section are unapproached by larger plate columns. Its truth is also well illustrated by the Podbielniak analytic column, where the liquid phase in process is extremely small, but in this case for the reason of minimising holdup. A more concrete illustration seems necessary to show that this point of view is really different.

If a feed consists of propane, butane and pentane, from which it is desired to remove propane at a suitable pressure, a kettle temperature may be learned, which if maintained will remove the propane with the desired completeness. Analysis will show that when such a result occurs, it is because the requisite amount of heat has been added and not because a requisite kettle temperature has been maintained, for if, while maintaining the same mol per cent. of propane in the feed and the same operating pressure, the feed be varied by increasing the pentane and reducing the butane in corresponding amounts, it will be found that the propane is no longer removed at the same kettle temperature. Examination will show that while the qualitative conditions are the same, the amount of heat supplied has been reduced and that sufficient propane has added itself to the mixture in the kettle to form a composition which will have the controlled temperature at the controlled pressure.

A recent paper by S. S. Smith,[11] President of the Natural Gasoline Association of America, discusses those types of operating control which have been used and describes also one based on the temperature difference between two selected points in the column. When one remembers that all that was thought necessary seven years ago was the occasional adjustment of kettle temperature, this paper is very significant. As indicating that the subject is still a live one, one of the trade journals, in reporting the discussion of the paper, says : " Some were of the opinion that many interlocking controls should be placed on the towers and auxiliary equipment, while others held that there was no need for so much control, but rather that some of the functions be permitted to vary at will, while keeping others constant."

The author believes that further progress in types of control based on physical properties of the products, and in details of design having to do with inherent operating stability and the closer approach to equilibrium at the plates, will mark progress of the near future. A tendency now gaining ground towards the utilisation of a suitable number of properly designed columns for the problem at hand is being less retarded by the precedent of taking of " pan cuts " which has been practised only with the longer boiling range commercial products. The lighter products have from the first been considered as individual members of a hydrocarbon series in greater or less purity, rather than as mixtures of such a boiling range. This point of view is becoming increasingly fixed, so that now one hears about the per cent. of propane or of butane in commercial motor fuel, whereas in 1923 its higher initial boiling point was thought by many persons, who would not admit the fact now, to indicate that neither was present.

It is obvious that the author's point of view is that of the natural gasoline manufacturer. While he believes that this industry has contributed largely to recent progress in rectification, he realises fully that this was due to working with a simple material containing a few components in reasonably large percentages and with widely different vapour pressures. The principles disclosed, however, are of universal truth. In their light much more difficult separations become possible, and if nature had to make the first easy material for us to work on, it is suggested that before concluding that a certain separation is impossible, we first use two or three columns to prepare a material containing the desired product in a concentration as great as that of butane in natural gasoline. Then its separation may not only be possible, but even commercially practicable.

[11] " Stabilizer Control." *Refiner*, June, 1931, **10** (6), 99–103.

The Determination of the Vapour Pressure of Gasoline according to the Method Used by the Bataafsche Petroleum Mij.*

In the examination of a gasoline for the purpose of preparing and controlling cargoes for shipments, calculation of evaporation losses, and pressures developed in storage tanks, etc., it is highly desirable to know the vapour pressure of the original gasoline before any appreciable amount has been evaporated.

Several methods are known for determining this " Initial Vapour Pressure." The present paper describes a method, worked out by the Bataafsche Petroleum Maatschappij, which has been in use for four years with complete satisfaction, and has proved to be capable of reaching a satisfactory degree of accuracy in a convenient manner.

In order to understand the following description it is necessary to define exactly the meaning of the term " Vapour Pressure " as used in this paper. This may be stated as : " The vapour pressure of a gasoline is the partial pressure of the hydrocarbons in vapour phase in equilibrium with the liquid." It will be seen that, according to this definition, all substances other than hydrocarbons, such as dissolved air, carbon dioxide, water, etc., are left out of consideration, and it follows that, in measuring the vapour pressure of a gasoline, precautions must be taken to exclude the effects of these substances.

It is obvious that, in measuring the " Initial Vapour Pressure " of a gasoline, the determination must be made with the least possible evaporation of liquid from the sample under examination. The " B.P.M." method excludes the effects of substances other than hydrocarbons, and is carried out with a minimum of evaporation of liquid from the sample.

The general principle involved is common to many methods of measuring vapour pressures, and is based on the increase in volume observed when a measured quantity of air is brought into contact with a gasoline and thoroughly saturated with its vapour, the pressure being kept constant. It is known that the increase in volume of the vapour space, at constant pressure, is a measure of the partial pressure of the evaporated hydrocarbons,

* Paper received October 2nd, 1931.

and by a simple calculation the "Vapour Pressure" may be found. This may be expressed by the equation:—

$$T = \frac{v}{a + v} \times p$$

where T = Vapour pressure of gasoline.

a = Air volume.

$a + v$ = Volume of air saturated with hydrocarbon vapour.

p = Pressure in reaction vessel.

In carrying out a determination based on the above principle, the vapour pressure of a gasoline is calculated from the increase in volume of the air originally introduced into a reaction vessel containing gasoline, and it is thereby assumed that this volume increase exclusively consists of gasoline vapour, and that the quantity of air remains entirely unchanged. In practice this will not be true, as gasoline always contains some air in solution, and the quantity of dissolved air, originally present in a sample, will never exactly correspond to the quantity remaining in solution in the final state of equilibrium, and, therefore, air will either be released or absorbed by carrying out the determination.

The gasoline will always retain air in solution (as also will the water which is used in the reaction vessel, although to a much smaller extent). When the added air is saturated with hydrocarbon vapour, and the equilibrium is attained at atmospheric pressure, the partial air pressure in the reaction vessel will, of course, be lower than the atmospheric pressure by an amount equal to the vapour pressure of the gasoline. The air remaining in solution in the gasoline and in the water is in each case proportional to the partial pressure of the air in the mixture of gasoline vapour and air. It follows that, in order to obtain exact results in measuring the increase in volume of the air/vapour space at equilibrium, it will be sufficient to bring the gasoline (before the actual determination) into a state of equilibrium in respect to the air absorbed therein at the partial air pressure in the reaction vessel at the stage of the final equilibrium.

This state of affairs is obtained by agitating a small volume of air with gasoline in a burette until a state of equilibrium is reached. The saturated air and vapour mixture is expelled from the burette, leaving the gasoline behind. A new measured quantity of air is introduced and a fresh equilibrium obtained. As the gasoline has not been in contact with air since the first equilibrium it will not have altered in respect to its absorbed air, and the addition of the new quantity of air will not give rise to absorption or release of air. The increase in volume as now measured will have been

exclusively caused by gasoline vapour, and will exactly indicate the quantity of gasoline vapour present. In this manner the present method excludes the effect of dissolved air, carbon dioxide, etc., on the measurement of the vapour pressure of a gasoline.

In order to prevent evaporation of liquid from the sample under examination, and so obtain the "Initial Vapour Pressure," the transfer of the sample into the burette is made by displacement from the sample container by means of water (as described later) out of contact with air. Loss of volatile fractions by pouring is, in this manner, avoided, and the gasoline should reach the burette in exactly the same condition as when it was in the original container.

During the experiment, in reaching the equilibria, a small quantity of hydrocarbons is, on each occasion, evaporated and expelled from the burette. When the total amount expelled is compared with the amount of liquid gasoline taken for the determination, however, it is evident that the proportion evaporated is extremely small, so that the vapour pressure found closely approaches the actual "Initial Vapour Pressure" of the sample.

Of course, there are possible blends—*e.g.*, of heavy gasoline with very volatile components—in which the slightest evaporation would cause considerable decrease in vapour pressure of the residues, but these may be left out of consideration as not being likely to occur in actual practice.

The following is a description of the apparatus used and the general procedure involved.

Sampling.—Considerable care must be taken in sampling gasoline for the determination of the "Initial Vapour Pressure" to avoid losses of lighter fractions. It is also important that the sample containers should be completely filled with gasoline.

Wherever possible an ordinary wide necked pint bottle, to which can be fitted the transfer device shown in the diagram (D), should be used as container. This transfer device consists of a cork to fit the sample container, holding a dropping funnel and delivery tube, transfers being made to the apparatus by running water from the dropping funnel into the container. If the container in which the sample is received is not of a size or shape suitable to take the transfer device, the necessary quantity of gasoline is siphoned from this container to a container of suitable size. To avoid losses during transfer by splashing, the siphon is set running free and the end pinched for a few seconds while it is placed under the surface of a quantity of water in the container. On resuming siphoning the final container fills without splashing or agitation of the gasoline sample.

Apparatus.—The apparatus consists of :—

A water-jacketed burette (capacity about 150 ml.)—A,

A water-jacketed burette (capacity about 25 ml.)—B,

A levelling bottle—C,

A transferring bottle—D,

A circulating pump—E,

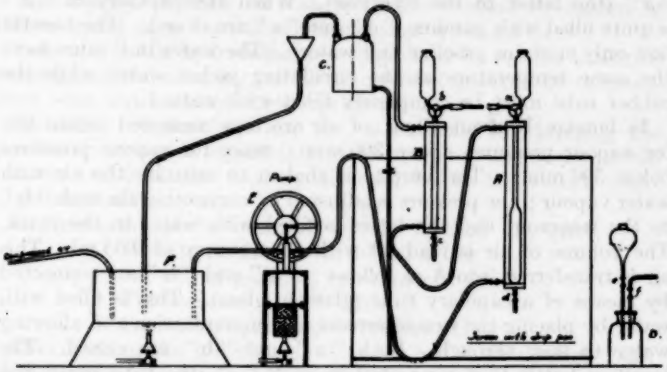
A constant temperature water bath with stirrer and electric heater—F,

and is arranged as shown in the attached sketch.

The Determination.—The accuracy of the determination is greatest when it is carried out at a temperature so chosen that the vapour pressure of the sample amounts to about 300 mm. of mercury ; lower and higher vapour tensions can be measured quite accurately, however. The temperature is kept constant to within 0·1° or 0·2° C.

Burette A is carefully rinsed out with acetone before each determination and then sucked dry or rinsed out with water. It is then completely filled with water.

About 10 ml. of air are measured in burette A (slightly less for vapour pressures above 300 mm. ; more for vapour pressures



APPARATUS FOR THE DETERMINATION OF VAPOUR PRESSURE

B.P.M. METHOD

below 300 mm.). The sample of gasoline is contained in the bottle D, which is completely filled with gasoline and water. The delivery tube " f " is connected to the three-way cock " a "

with a rubber tube. Water is admitted into bottle D through cock " e " so as to drive all air from " f " and the rubber tube through cock " a " out into the small reservoir fixed to the top of the burette. (The connections are thereby completely filled with gasoline.) By manipulating cock " a " and opening " d," gasoline (about 125 ml.) is admitted into burette A without allowing air to escape. Cocks " a " and " d " are then closed. The burette is now removed from its stand and shaken ; the surplus pressure is let off by allowing water to run out at " d," during which operation the burette should not be vertical but inclined (cock " d " must always be somewhat lower than " a," however). This prevents a considerable sub-pressure in the burette. When, on repeated shaking, no water flows from " d," the pressure is adjusted by connecting the burette to the small reservoir (*i.e.*, with " a " open), which must remain filled with water to a definite mark. " a " is now closed again, the burette shaken and the pressure again adjusted as described. This is repeated until water now no longer flows into the burette on opening " a." (During shaking, the reservoir is closed with a cork carrying a capillary tube.)

When the volume of vapour is constant, the first reading is terminated. This only serves to bring the gasoline into equilibrium with a certain volume of air. The vapour is expelled by connecting levelling bottle C to cock " d " and by adjusting cocks " d " and " a " (the latter to the reservoir). When the capillary of " a " is quite filled with gasoline, " d " and " a " are closed. The burette now only contains gasoline and water. (The water in C must have the same temperature as the circulating jacket water, while the rubber tube must be completely filled with water.)

In burette B about 10 ml. of air are now measured (again less for vapour pressures above 300 mm. ; more for vapour pressures below 300 mm.). The burette is shaken to saturate the air with water vapour ; the pressure is adjusted by connecting the cock " b " to the reservoir, and the latter is filled with water to the mark. The volume of air is read off with an accuracy of 0·05 ml. This air is transferred into A as follows : " a " and " b " are connected by means of a capillary tube (glass to glass). This is filled with water by placing the two reservoirs in communication and allowing water to flow through. Both " a " and " b " are closed. The levelling bottle C is connected to cock " c" (the tube must first be filled with water). Cocks " c," " b," " d " and finally " a " are now adjusted so that all the air (and some water) is transferred from B to A. Cocks " a " and " d " are then closed and the burette B is disconnected. The burette A is shaken as previously described, the pressure being adjusted successively by means of cocks " d " and " a " until no water flows out or in respectively.

The final volume is read off to within 0·05 ml. The total volume of vapour should at the most be about 25 ml. If now :—

a ml. of air were measured off in burette B ;

v ml. is the increase in volume in burette A ;

p mm. is the pressure in burette B (= atmospheric pressure + head of water in reservoir ; the latter is usually equivalent to 9 to 10 mm. of Hg.) ;

w mm. is the vapour tension of water ;

the vapour pressure P of the gasoline at the temperature of the experiment will be given by :—

$$P = \frac{v}{a + v}(p - w) \text{ mm. of Hg.}$$

The same operation as described above is twice repeated—*i.e.*, the vapour is expelled, new air introduced, equilibrium established, and P determined. These values should not differ materially. If there is too large a divergence, a fourth determination should be made, and the results of the three determinations which agree the most closely accepted as the true vapour pressure.

Summary.—The present paper describes a method for measuring the vapour pressure of a gasoline in which the losses of volatile fractions are minimised and the effect of dissolved air, carbon dioxide, water, etc., is excluded.

The method depends on measuring the increase in volume of the air space in a burette when agitated with gasoline.

Loss of volatile hydrocarbons is minimised by special attention to sampling and carrying out all transfers of gasoline by displacement with water out of contact with air.

The effect of dissolved air, etc., is excluded by bringing the gasoline under test in equilibrium with air, water, etc., at the partial pressure of air at the final equilibrium, before the actual determination is made.

Experimental results obtained by the method are given :—

Burette A, filled with 10 ml. of air ;
135 ml. of gasoline, remainder water ;
Temperature = 24·9—25·0° C.
Barometric pressure = 750 mm. Hg.

After shaking the burette and draining off water through "d", the following readings are obtained :—

19·8, 22·1, 23·4, 23·8 and 24·0.

No more water flows out of "d". After shaking the burette again and connecting it to the reservoir, the following readings are obtained :—

22·2, 30·8, 19·2, 18·3, 17·6, 17·4, 16·7, 16·6, 16·4, 16·2, 16·15 and 16·15 respectively.

Determination.—The gas-air mixture is then expelled by water pressure and 9·90 ml. of air is measured off in burette B.

After passing this air into burette A, shaking the burette and draining off the water through "d", the following readings are obtained :—

15·0, 16·0, 16·8, 17·8, 18·4, 18·6.

No more water flows out of "d". After shaking the burette again and connecting it to the reservoir, the following readings result :—

17·4, 17·2, 17·1, 17·0, 16·9, 16·85 and 16·85.

The vapour pressure at 25° C. is then :—

$$\frac{16{\cdot}85 - 9{\cdot}90}{16{\cdot}85} \times (750 + 9 - 23{\cdot}5)$$

$$= \frac{6{\cdot}95}{16{\cdot}85} \times 735{\cdot}5 = 303 \text{ mm. Hg.}$$

Duplicate.—Measured off 10·05 ml. of water.

Found after shaking and draining off through "d" :—

16·0, 16·6, 17·2, 18·6, 19·0, 19·2 and 19·4 ;

and after shaking again and connecting to the reservoir :—

18·4, 18·0, 17·8, 17·4, 17·05, 17·05 and 17·05.

Vapour pressure at 25° C. :—

$$\frac{17{\cdot}05 - 10{\cdot}05}{17{\cdot}05} \times (750 + 9 - 23{\cdot}5)$$

$$= 302 \text{ mm. Hg.}$$

Triplicate.—Measured off 10·00 ml. of water.

Found after shaking and draining off through "d" :—

15·0, 17·2, 18·4, 19·0, 20·0, 20·2, 20·4 ;

and after shaking again and connecting to the reservoir :—

19·0, 18·2, 17·6, 17·3, 17·2, 17·1, 17·05, 17·05, 17·05.

Vapour pressure at 25° C.

$$\frac{17{\cdot}05 - 10{\cdot}00}{17{\cdot}05} \times (750 + 9 - 23{\cdot}5)$$

$$= 304 \text{ mm. Hg.}$$

Average value of determinations :—

$$\frac{303 + 302 + 304}{3} = 303 \text{ mm. Hg.}$$

In conclusion, we beg to thank the Directors of the Bataafsche Petroleum Mij. for their kind permission to publish these results.

A Selective Method of Acid Treatment for the Refining of Vapour Phase Cracked Distillates.*

By E. Retailliau.

In recent years there has been a decided trend towards production of motor fuels of higher anti-knock value, and this tendency has been reflected in numerous modifications in the operation of liquid phase cracking processes to increase the anti-knock property of the cracked gasoline. It has also resulted in an increased interest in vapour phase cracking processes because the latter produce gasolines of greater anti-knock value than do the liquid phase cracking processes and therefore vapour phase cracked gasoline has been used more and more for preparing high anti-knock fuels.

The greater anti-detonating qualities of vapour phase cracked distillates are due to their greater content of unsaturated and aromatic hydrocarbons, but at the same time these distillates contain a greater proportion of unstable and therefore undesirable unsaturates than do the liquid phase cracked distillates. For this reason, vapour phase cracked distillates are more difficult to refine and a large amount of work has been conducted on methods of treating vapour phase cracked distillates.

As the result of considerable research, the method described in this paper was developed.

Theoretical Basis.

The whole problem of treating vapour phase cracked distillates is one of polymerization, even more than in the case of liquid phase cracked distillates, because the amount of unsaturates and aromatics is much greater in the former than in the latter case. In devising a method for vapour phase cracked distillates, it has been kept in mind that the compounds to be removed during the treatment are chiefly those causing gum formation, which leads to objectionable deposits in engine operation and those causing discolouration of the gasoline upon storage. The various steps in the process will be dealt with in order.

In the course of work carried out on various kinds of cracked distillates, it was observed that the use of concentrated solutions of caustic soda is highly beneficial in regard to the ease of their further refining. The removal of hydrogen sulphide by various means, such as dilute caustic soda solution, milk of lime or sodium

* Paper received November 17, 1931.

carbonate solution, has long been practised in the oil industry, and this phase of the problem is so well known that it will not be considered in this work.

Cracked distillates, especially those from vapour phase cracking processes, after being freed from their hydrogen sulphide content by any one of the usual methods, are advantageously treated with caustic soda solution of high concentrations, such as 35 to 50° Bé. This treatment not only results in a practically complete removal of the naphthenic or other acids present in the cracked distillates, but also in the polymerization of certain unstable unsaturated compounds, possibly of the terpene series. The polymerized material so obtained usually forms an oily layer, insoluble in both the aqueous solution and the cracked distillate ; the type of crude used as well as the conditions of cracking may, of course, cause a wide variation in the amount and physical aspect of this oily layer, which may vary from a very mobile liquid to a material of the consistency of asphalt. It may be of interest to indicate that this polymerized layer is quite sensitive to the oxidizing action of air, and if it is left standing in contact with air, it gradually becomes more and more viscous until it becomes similar in appearance to a hard asphalt. It was observed in some cases that this insoluble layer was not constituted of a true oil, but of sodium salts of naphthenic acids, which dissolved readily upon dilution with water.

In this connection it may be interesting to recall the statement made recently at the American Chemical Society Meeting at Buffalo by Prof. Bailey, that naphthenic acids may be formed by atmospheric oxidation of unsaturates in presence of caustic soda. Of course, there is only a small amount of oxygen present in the case of the cracked distillates under consideration here, but it does not seem impossible that some naphthenic acid formation may take place during contacting with strong caustic soda solution.

In the United States 66° Bé. acid is quite commonly used for treating liquid phase cracked distillates, the amount used varying with the origin of the crude from which the cracked distillate was produced and also with the sulphur requirements. Such a concentration of sulphuric acid reacts so violently with vapour phase cracked distillates that considerable heat is evolved, resulting in such large losses as to make it impracticable from an economical point of view. Besides, the valuable constituents of the vapour phase cracked distillates are detrimentally affected by such a treatment and the anti-knock value of the finished gasoline may be considerably reduced.

When it is considered that many vapour phase gasolines have a high anti-knock value, although they contain a very small proportion of aromatics, it is likely that such gasolines contain a large

amount of secondary or tertiary aliphatic hydrocarbons, both unsaturated and saturated, which is in line with the most recent work published on the theory of cracking as well as on the properties of the various classes of hydrocarbons.† It has long been known that substituted olefins, for instance substituted amylenes, and also terpenes are reacted upon by sulphuric acid even of low concentration to form the corresponding alcohols, while concentrated sulphuric acid causes the formation of various polymers from these same hydrocarbons. With this in mind, the development of a selective method of acid treatment was undertaken in which the various objectionable compounds would be successively removed by the use of increasing concentrations of sulphuric acid. When using such a procedure, the weaker concentration of acid removes the most unstable unsaturates without causing any considerable evolution of heat and without removing useful compounds. This removal makes the subsequent reaction with a stronger acid less violent and thus diminishes local superheating, thereby reducing polymerization of the useful compounds.

Besides this removal of the most unstable unsaturates, a dilute sulphuric acid solution has also the advantage of removing organic nitrogen bases, which may be present and which are objectionable in the finished product because they are of bad odour and cause poor colour stability. When no dilute sulphuric acid solution is used, the nitrogen bases may not be entirely removed by the strong acid because the latter causes almost instantly the formation of polymerized material, which forms a sort of protective film around the small acid globules thus decreasing the refining action of the latter. Large amounts of concentrated acid remove these bases entirely, but it is obviously advantageous for economical reasons to use the smallest amount possible.

When the more unstable and reactive unsaturates have been removed, a sulphuric acid of higher concentration can be used to complete the refining of the cracked distillate without causing the disadvantages mentioned above. However, it is desirable to use concentrations lower than 66° Bé. in order to minimize the removal of the useful constituents of the gasoline and an acid somewhat weaker (75 to 85 per cent. H_2SO_4) is best suited for this purpose. As the decrease in concentration of the acid causes a considerable reduction in the speed of the reaction taking place between the distillate and the acid, it is necessary to carry out this latter treatment at elevated temperatures which enables the removal of the

† "Detonation Characteristics of Some Paraffin Hydrocarbons" and "Detonation Characteristics of Some Aliphatic Olefin Hydrocarbons" by Wheeler G. Lovell, John M. Campbell and T. A. Boyd, *Ind Eng. Chem.*, 1931, **23**. 26 and 555.

objectionable compounds without causing appreciable losses of useful hydrocarbons.

Although the above principles seem applicable to any kind of cracked distillate, the best conditions of treatment, as far as temperature, concentration of acid, time of contact, etc., are concerned, may differ widely for distillates produced from various cracking processes or under different cracking conditions, not to mention the origin of the cracking stocks, etc. It is best to determine the optimum conditions by experiments with the distillate to be refined. The various factors involved usually have to be kept within fairly narrow limits. A good correlation can be established between laboratory and plant results.

Contrary to the procedure still practiced in many refineries, the acid treated distillate is not washed with water before being neutralized, but is directly neutralized with caustic soda solution of high concentration after the proper time of settling. Certain odoriforous and coloured compounds are returned to the gasoline fraction by a water wash while they remain in the caustic soda sludge by the procedure indicated. It was also found that a neutralization at elevated temperature had some advantage over neutralization conducted in the cold.

Method of Treatment.

The following method is a specific example of such a selective method applied to a vapour phase cracked distillate which had given an unsatisfactory gasoline by other refining methods. The quantities of acid given below refer to equivalent amounts of 66° Bé. acid.

The cracked distillate is treated in a very efficient mixing device with about 0·1 lb./bbl. of caustic soda in 40° Bé. solution.

After settling, the distillate is treated with about 1·4 lb. per barrel of 30 per cent. sulphuric acid. From this weak acid solution, it is possible to separate alcohols and organic nitrogen bases, thus showing that this dilute acid has removed at least some of the most unstable and objectionable compounds.

The distillate is then heated to a temperature between 125 and 175° F., as determined by previous experiments, and treated with 3 to 12 lb. per barrel of sulphuric acid of concentration not higher than 90 per cent. and preferably about 75 per cent.

The acid treated distillate is then settled and treated at the same temperature with 0·3 lb. per barrel of caustic soda in 40° Bé. solution.

While cracked distillates after acid treatment at ordinary temperature show only a darkening in colour compared with the untreated material, a different effect is observed when the above

method of treatment is used. The acid treated distillate has a colour varying from light green to purple after the acid treatment, and this colour turns to a more or less deep shade of red. Also, while the acid sludge obtained in the treatment of liquid phase cracked distillate at ordinary temperature has a pungent unpleasant odour often accompanied by a small evolution of sulphur dioxide, the acid sludge obtained from the above treatment of vapour phase cracked distillate has a rather terpenic odour which is not unpleasant and no evolution of sulphur dioxide can be detected unless this sludge is exposed to air for a time.

The treated distillate obtained is then re-run to obtain a finished gasoline. Low temperature distillation has long been recommended for the production of gasoline, either from crude oils or from treated cracked distillates because the decomposition of unstable compounds is greatly reduced by such a procedure and it is obviously desirable that this distillation method be used when more delicate stocks, such as vapour phase cracked distillates, are used. A low temperature distillation is carried out either in one stage under atmospheric pressure, when a large amount of steam will be required, or partly under atmospheric pressure with a small amount of steam and partly under reduced pressure.

Conclusions.

Vapour phase cracked gasoline of 205° C. final boiling point has been produced by this method of treatment on a plant scale with the following properties :—

Initial Colour	29 Saybolt.
Colour Stability in Light ..	Good—Dropped 2 to 3 points after two weeks exposure to sunlight.
Total Sulphur Content ..	0.09%.
Gum Content (glass dish) ..	Less than 5 milligrams per 100 ml.
Bromine No.	99.
Unsaturates and Aromatics ..	53% by volume.
Aromatics	16% by weight.
Reid Vapour Pressure at 100° F.	6.8 lbs./sq. in.
Ricardo H.U.C.R.	6.0 to 6.2.
C.F.R. Octane No. at 212° F.	About 82.
Freezing Point	Below —70° F.
Cloud Point	—50° F.
Aniline Cloud Point	+15° C.

It is not without interest to indicate here one of the great advantages of such a selective method of acid treatment. The successive removal of the various objectionable constituents of the gasoline is made without local overheating of the distillate and, therefore, the useful constitutents remain unaltered. This point is quite well evidenced by the very small reduction in bromine number of the gasoline so treated as compared to that of the

gasoline distilled from the untreated distillate from which it was made. While the acid treatment of cracked distillate in the cold with 66° Bé. acid usually removes small amounts of aromatics, with this treatment at elevated temperature and with smaller concentrations of acid, the aromatics are retained in the gasoline. The reduction in anti-knock value is therefore extremely small, usually not more than 2 to 5 C.F.R. octane numbers difference between treated and untreated distillates of the same volatility.

The value of the copper dish gum test for judging vapour phase cracked gasoline is problematical. However, it may be of interest to note that experimental batches of vapour phase cracked gasoline, produced by a similar method to the above, and containing 200-300 milligrams of copper dish gum per 100 ml., after blending with 70-80 per cent. of straight run gasoline, gave a copper dish gum content on the blend of less than 10 milligrams per 100 ml., that is to say, considerably below the expected figure.

While considerable progress has been made in the treatment of vapour phase cracked distillates, the subject is still a fruitful one for further research. Future work may develop methods of preparing spirits for special purposes, and useful by-products, such as varnishes. Patent protection for the working of this process has been applied for in various countries.

The author wishes to express his indebtedness to the management of the Royal Dutch Shell Group for permitting the publication of this work.

REVIEWS

Chemical Encyclopædia—A Digest of Chemistry and Its Industrial Applications. By C. T. Kingzett, F.I.C. Fifth edition. Pp. 1014. London: Balliere, Tindall & Cox. 1932. 40s. net.

The fact that this work has now passed into a fifth edition is ample evidence of its value as a ready means of reference to the physical and chemical properties of a multiplicity of substances. There is a definite need for an epitomised digest of chemistry and its industrial applications.

Naturally, from the point of view of the petroleum chemist, chief interest lies in the reference to mineral oil and its derivatives. Examples follow which indicate the reliability to be placed on the information afforded.

Under the heading "Petroleum" it is stated that mineral oil occurs "mainly in rock formation of either the Tertiary or Carboniferous periods, sometimes in beds or lakes as in Trinidad, and at other times flowing from clefts of rocks or deep wells . . . particularly between Pittsburg and Lake Erie. Deposits also occur in Canada . . . and to a small extent in Dorset, Norfolk and Nottingham."

"The crude oil can be purified to some extent by percolation through fuller's earth or specially prepared bauxite."

"The Frasch process . . . for certain reasons is not suitable for the treatment of crude Mexican oil.

"Sodium plumbite . . . removes sulphur compounds such as hydrogen sulphide."

"Crude petroleum is used to some extent as a substitute for coal in locomotives."

"The benzene (*sic*) . . . requires no chemical treatment and is largely used as motor spirit."

"Paraffin wax is separated by cooling the higher distillate to 7° C."

"The value of motor spirit to-day must be based on its ability to withstand high compression and not on its latent heat."

"In the refining of crude oils the so-called hypochlorite process has been adopted."

"It is stated that the manufacture of cracked gasoline now exceeds the production of the product yielded by the original distillation of petroleum."

Too much attention, however, should not be paid to matters of specialised detail—and the book is not written for specialists. As the author justly points out "apart from its value to manufacturers and all engaged in the study, practice and application of chemistry . . . it will . . . secure greater use by

politicians, journalists, teachers, lawyers, merchants, brokers, medical practitioners, pharmacists, company directors and other sections of the professional and cultured classes."

It should finally be said that the book is most admirably printed and produced. A. E. DUNSTAN.

OIL ECONOMICS. The Application of Economic Facts and Principles to the Problems of Management and Investment in the Petroleum Industry. By Campbell Osborn. Pp. 402. London: McGraw-Hill Publishing Co., Ltd. 1932. 24s. net.

The economics of petroleum attract ever-increasing attention, due to the persistent efforts of many to circumvent the normal working of the law of supply and demand. This applies more particularly to U.S.A., where the balance has been most upset and a highly dangerous situation created by an uncertain potential. Mr. Osborn has approached the subject of his book in a very practical and comprehensive way by securing the collaboration of many leaders in the oil industry in America, and the views expressed may be considered to have the support of many distinguished representatives of the U.S.A. oil industry. The work has been divided into eighteen chapters in an effort to separate the different subjects which in turn come under review, but many are so closely interlocked that the attempt has only been partially successful and there is, in consequence, unavoidable overlapping.

A profound knowledge of the oil industry and its customs is betrayed, and the author succeeds in establishing his point of view that only by an assemblage of reliable facts and figures covering a long period can the future trend of prices and events be approximately predicted. The many factors which govern price fluctuations are discussed from various angles, and no important branches of the oil industry have escaped considered notice. Whilst pleading for "free, open and fair and carefully guarded competition," he insists that it must be tempered by sensible co-operation with a minimum of official interference. No indication is given of how these conflicting points of view might be harmonised, and herein lies the cause of the major troubles of the industry to-day.

The manner in which gasoline production has been the dominant factor in guiding oilfield and refinery technique is clearly shown, and figures are given to substantiate the statement. "Putting America on wheels" has been the major cause of the gasoline demand, for no less than 26,662,000 motor vehicles were registered in 1930, and the domestic demand of gasoline was 1,022,000 barrels a day.

Figures are presented to show that substantial losses have been sustained by oil producers in the past, and the author comments on the unfairness of fate in according to the most hazardous branch of the industry the least reward. The capitalization and revenue of old-established and seasoned oil companies interested in all branches of the industry is compared with those of newer origin, and the author shows that whereas formerly extensions

were financed out of profits, these proved quite inadequate in recent years, and big demands were made on the public for new capital.

Future markets for petroleum products receive very full consideration, but predictions are tempered with caution as the future is not easy to forecast. The world depression has delivered a very decisive check to normal expansion of motor vehicles. Like many others, the author questions whether new major pools can be discovered indefinitely to sustain output on the present large scale, and he extends little hope that other sources of liquid fuel supply, such as coal, oil shale and alcohol, will compete with natural oil in the near future.

Many useful facts and figures are given concerning leasing customs, royalty questions, production costs, yields of wells, transportation and storage of oil and such-like matters, and useful graphs and tables are introduced in support of contentions. Special attention is called to the high cost of storing oil which was at one time so prevalent when cheap flush production was available during the opening of new pools.

Brief but very clear accounts are included of all the important operations connected with the recovery and treatment of petroleum. Cracking methods receive particular notice as the limits of possibilities in this direction are still, it is thought, far from reached.

Price movements of crude oil and refined products are critically analysed in two chapters, and when discussing the subject of cracking, the author refers to the difficulty of forecasting its ultimate influence, not only on gasoline supplies and prices, but on fuel oil and other products which can be employed as cracking stock.

The future of the service station and the difficulties occasioned by keen and ill-considered competition are specially emphasised when dealing with the subject of marketing gasoline and other products.

When dealing with natural gas the interesting information is vouchsafed that the average price to domestic consumers has steadily risen from 23 cents per 1000 cu. ft. in 1906 to 60 cents to-day, the average annual gas bill of a householder being $45.

The economic control of operations is skilfully handled. Efficiency and economy are, it is pointed out, relative terms. Some companies are efficient and economical in some branches and wasteful in others, and the dangers of being led into extravagant payment for lease bonuses and rental is one to be guarded against. A warning is sounded regarding the harm caused by inventory speculation in the sales department, the withholding of stocks for better prices causing heavy losses at times.

The valuation of oil and gas lands receives attention, and the subject of oil securities is concisely treated. Foreign oil conditions are the subject of fair comment in a brief chapter, but no guess is hazarded of probable reserves outside U.S.A.

The pros and cons for proration are critically considered and the dangers attending compulsory artificial control are emphasised. No less than 49 tables comprise the appendix at the end of the book, and these will be found of great value to all interested in oil problems.

"Oil Economics" is worthy of a place on the bookshelf of all associated with oil. It is lucidly written, clearly printed, remarkably free from errors, and gives a concise account of the economics of the many branches of the industry.

A. BEEBY THOMPSON.

HANDBOOK FOR ELECTRIC WELDERS. Pp. 91. London: Murex Welding Processes, Ltd. 1932. 1s. net.

This small handbook has been written with the object of providing an elementary and concise account of the principles of arc welding. A series of short practical instructions for various types of work is included and illustrated. The book should prove of value to the operator and to the user of arc-welding processes.